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GEOLOGICAL SURVEY OF OHIO

EDWARD ORTON, JR., State Geologist

FOURTH SERIES, BULLETIN No. 4.

THE
LIMESTONE RESOURCES
AND THE
LIME INDUSTRY IN OHIO,

BY

EDWARD ORTON, JR., E. M., and SAMUEL VERNON PEPPEL, B. Sc.

Published by Authority of the Legislature of Ohio, Under the Supervision of
the State Geologist.

COLUMBUS OHIO, JULY, 1906

Printed by the Springfield Publishing Company, Springfield, Ohio.
Maps and Illustrations Engraved by the Bucher Engraving Company, Columbus, O.
Bound at the State Bindery, Columbus, Ohio.

LETTER OF TRANSMITTAL.

To His Excellency, ANDREW L. HARRIS, *Governor of Ohio:*

SIR:—I have the honor to present to you, herewith, Bulletins 4 and 5 of the Fourth Series of publications of the Geological Survey of Ohio. The subject of Bulletin 4 is the Limestone Resources and the Lime Industry in Ohio; part of it has been prepared by Mr. Samuel V. Peppel, B. Sc., part of it by myself, and part of it by Mr. Peppel and myself jointly. The subject of Bulletin 5 is the Manufacture of Sand-Lime Brick, and is the work of Mr. Peppel alone. These two reports were begun in 1901, and several delays have occurred in the course of the work. It is confidently believed, however, that the value of the work as finally completed has justified all the delays, as much of the most valuable material has been obtained very recently. It is hoped that these two Bulletins will find a rich field of usefulness in an industry of which comparatively little has been written.

I have the honor to be,
Yours very respectfully,
EDWARD ORTON, JR.,
State Geologist.

Ohio State University,
June, 1906.

85314.

OFFICERS OF THE SURVEY.

EDWARD ORTON, JR., E. M .... State Geologist
Economic Work in Cement and Clay Industries.

CHARLES SMITH PROSSER, M. Sc........................ Assistant Geologist
Areal and Stratigraphical Geology.

JOHN ADAMS BOWNOCKER, D. Sc........................ Assistant Geologist
Economic Work in Oil, Gas, Salt and Coal.

NATHANIEL WRIGHT LORD, E. M........................ Consulting Chemist
Economic Work on Constitution and Utilization of Coals.

SAMUEL VERNON PEPPEL, B. Sc........................ Special Assistant
Technological Work in Lime and Sand Brick Industries.

GEORGE DAVIS HUBBARD, Ph. D........................ Assistant Geologist
Preliminary Work on Physiography of Ohio.

LEWIS GARDNER WESTGATE, Ph. D...................... Assistant Geologist
Areal Geology of the Delaware Quadrangle.

MRS. R. W. McCLELLAND........................ Stenographer and Clerk

ANNOUNCEMENTS BY THE STATE GEOLOGIST.

BULLETIN FOUR.

The mineral wealth of Ohio is nowhere of a showy or spectacular variety. No gold or silver in economic quantities occurs in our borders. No copper, lead, tin, zinc or metals other than iron can profitably be extracted from our rocks. As a consequence, the people of Ohio have been comparatively free from those spasms of unreasoning excitement and sensational financiering which have characterized the development of the mineral resources of many of the western states. The mineral resources of Ohio are all of the plain, unromantic and everyday sort, which appeal to the speculator and promoter but little, and to the credulous public still less.

Notwithstanding these facts, they constitute an asset of immense present and future importance to the people, guaranteeing great and permanent industries founded on the daily needs of the civilized world. Such industries are of infinitely more value than the richest mines of precious minerals could be, for they require honest, economical management to make success possible, and thus develop the thrift, industry and self-reliance of the great masses of the people and the technical knowledge of the engineer, chemist and manager, as well.

The present Bulletin is devoted to a discussion of one of the commonest, most familiar and least appreciated branches of the mineral industry—the occurrence and exploitation of limestone, and a consideration of the place which its products are playing in our modern life. The uses of limestone for roads, foundations, buildings, and the manufacture of mortar has been so long a familiar thing that it has lost all glamour or interest to most people. Moreover, the art of burning lime has been practiced in so crude a way, and by such untaught persons, that it has been taken for granted by many that there is nothing in it which can furnish food for thought, or study, or in any way repay the attention of the scientist or engineer.

It is scarcely necessary to say that this conception is wholly erroneous, and that the winning and burning of lime really affords full scope for the best chemical and engineering skill which can be brought to bear upon it.

The present volume was originally undertaken chiefly as a complement to Bulletins II and III, on the cement industry, and was designed as a dissertation on the resources of Ohio in cement material.

The first four chapters are largely written from this point. But as the work progressed, the importance of the other phases of the subject became increasingly apparent, and the publication has been greatly delayed in order to permit the preparation of chapters 5 and 6, dealing chiefly with the Technology of the Lime Industry. In the opinion of the writer, these two chapters, which have been prepared by Mr. S. V. Peppel, are a great step in advance in the literature of the lime industry, and their importance and value to lime makers and lime users will be at once recognized.

A fuller statement of the reasons for presenting this report at this time will be found in the introduction, Page 17.

BULLETIN FIVE.

In addition to a consideration of the lime industry, it was thought advisable to take up at the same time the consideration of a parallel or affiliated industry, the Manufacture of Sand-Lime Brick. For several reasons these two Bulletins have been bound together in one cover.

A fuller statement of the reasons for taking this subject up in detail will be found in the Preface on page 9.

FORMER PUBLICATIONS OF THE SURVEY.

The work performed by the First, Second and Third organizations of the Geological Survey of Ohio is comprehended in the following list of publications:

FIRST GEOLOGICAL SURVEY 1837-1838

Title of Volume.	Date of Issue.	Number of Pages.	Number of Copies Printed.	Geologist in Charge.
First Annual Report........	1838	134	5,000	W. W. Mather
Second Annual Report......	1838	236	5,000	W. W. Mather

SECOND GEOLOGICAL SURVEY 1869-1888.

Title of Volume.	Date of Issue.	Number of Pages.	Number of Copies Printed.	Geologist in Charge.
Report of Progress.........	1869	176	14,500	J. S. Newberry
Report of Progress.........	1870	568	14,500	J. S. Newberry
Report of Progress.........	1871	3	400	J. S. Newberry
Geology of Ohio, vol. I, part I, Geology...............	1872	680	20,000	J. S. Newberry
Geology of Ohio, vol. I, part II, Paleontology	1873	*401 †49	20,000	J. S. Newberry
Geology, of Ohio, vol. II, part I, Geology...............	1874	701	20,000	J. S. Newberry
Geology of Ohio, vol. II, part II, Paleontology	1875	*431 †59	20,000	J. S. Newberry
Geology of Ohio, vol. III, Geology	1878	958	20,000	J. S. Newberry
Geological Atlas of Ohio....	1879		5,000	J. S. Newberry
Geology of Ohio, vol. IV, Zoology and Botany......	1882	1,070	20,000	J. S. Newberry
Geology of Ohio, vol. V, Economic Geology...........	1884	1,124	10,000	Edward Orton
Preliminary Report on Petroleum and Inflammable Gas	1886	76	2,500	Edward Orton
Geology of Ohio, vol. VI, Economic Geology.......	1888	831	15,000	Edward Orton

*Pages. †Plates.

THIRD GEOLOGICAL SURVEY 1889-1894.

Title of Volume.	Date of Issue.	Number of Pages.	Number of Copies Printed.	Geologist in Charge.
First Annual Report........	1890	323	10,000	Edward Orton
Geology of Ohio, vol. VII, part I, Economic Geology.	1893	290	2,500	Edward Orton
Geology of Ohio, vol. VII, (complete including part I)	1894	970	7,500	Edward Orton

FOURTH GEOLOGICAL SURVEY 1899———

Title of Volume.	Date of Issue.	Number of Pages.	Number of Copies Printed.	Geologist in Charge.
Bulletin 1—Oil and Gas.....	1903	320	8,000	Edward Orton, Jr.
Bulletin 2—Uses of Cement..	1904	260	6,000	Edward Orton, Jr.
Bulletin 3 { Manufacture of Cements	1904	391	4,000	Edward Orton, Jr.
Bulletin 4 { Limestones and Lime..........	1906	365	4,000	Edward Orton, Jr.
Bulletin 5—Sand-Lime Brick	1906	79	4,000	Edward Orton, Jr.
Bulletin 6—Bibliography ...	1906	—*	3,500	Edward Orton, Jr.
Bulletin 7 { Nomenclature of Geological Formations....	1905	36	3,500	Edward Orton, Jr.
Bulletin 8 { Salt Deposits and Salt Industry........	1906	42	3,500	Edward Orton, Jr.

*In press.

DISTRIBUTION OF REPORTS.

First Geological Survey.—These volumes are out of print and rare. They can only be procured from dealers in second-hand libraries and are difficult to obtain even there.

Second Geological Survey.—These volumes were all distributed at the time of their issue. The State retained no stock for meeting future demands, so that no copies of any of these volumes can be obtained from the office of the State Geologist. They can be bought in many second-hand book stores, and from dealers in old libraries, at prices ranging from a few cents to two or three dollars per volume, according to rarity and demand. Volumes V and VI are the rarest and most sought for.

Third Geological Survey.—These volumes were all distributed at the time of issue, except Vol. VII, of which 1,500 were put in the hands of the Secretary of State, for sale at the cost of publication. Of these, a few remain at the date of the publication of this volume. The price is $1.50. To obtain copies, send postal or money order to the Secretary of State, State House, Columbus, Ohio. No other volumes can be obtained from this source.

The other volumes of this series can be procured only from second-hand book and library dealers.

Fourth Geological Survey.—Under the law, copies of these Bulletins can be bought at the office of the State Geologist at the cost of publication. Postal orders, money orders, checks, drafts, or currency must accompany orders. Stamps will not be received.

Bulletin 1—Oil and Gas	$ 0.65
Bulletin 2—Uses of Hydraulic Cements	0.30
Bulletin 3—Manufacture of Hydraulic Cements	Issue exhausted.
Bulletin 4—Lime Resources and Lime Industries	———
Bulletin 5—Lime-Sand Brick Industry	———
Bulletin 6—Bibliography of the Geology of Ohio	———
Bulletin 7—Revised Nomenclature of the Ohio Geological publications	0.06
Bulletin 8—Salt Deposits and Salt Industry in Ohio	———

LAWS UNDER WHICH THE SURVEY OPERATES.

For the information of the public, the law under which the work of the Survey is prosecuted is herewith published:

Laws of Ohio, 1889, Vol. 86, p. 262.
(Senate Bill 409.)

AN ACT

To provide for the extension of the Geological Survey of the State.

Section 1. Be it enacted by the General Assembly of the State of Ohio, That the governor is hereby authorized to appoint a state geologist, whose duty it shall be to continue and extend the investigations already made into the geological structure and resources of the state. Said state geologist shall be appointed for a term of three years, but he may be removed for cause at any time, and a successor appointed in his stead; and the governor is authorized to fill any vacancy which may occur from any cause, at any time. The compensation of said state geologist shall be at the rate of two hundred dollars per month, for the time actually employed; and said geologist shall have power to employ such assistants as he may need; but in no event shall the salary of the geologist, pay of assistants, and expense of the department, exceed the amount of the expenditure authorized by the general assembly.

Section 2. It shall be the duty of said geologist to study, and determine as nearly as possible, the number and extent of the various formations of the state; to represent the same, from time to time, upon properly constructed maps and diagrams; to study the modes of occurrence and the distribution of the useful minerals and products of these formations; to determine the chemical composition and structure of the same; to investigate the soils and water supply of the state; and to give attention to the discoveries of coal, building stone, natural cement, petroleum, gas and other natural substances of use and value to the state. He may also collect and describe the fossils of the various geological formations of the state; but no expenditure shall be incurred under this head that is not expressly ordered and provided for by the general assembly.

Section 3. The said geologist shall make, on or before the first day in February of each year. a report to the governor, covering the work of the preceding year, and the report shall be transmitted to the general assembly, to be printed in the same manner as other public documents, or as shall be otherwise ordered.

Section 4. The salaries of the state geologist, and the assistants employed by him, together with the traveling and incidental expenses, shall be paid monthly, on presentation of properly itemized vouchers, signed by the governor, out of the state treasury, from the appropriation made for such purpose.

Section 5. There is hereby appropriated from the general revenue fund the sum of one thousand dollars annually, for the purpose above named.

Section 6. This act shall take effect and be in force from and after its passage.

NOAH H. ALBAUGH,
Speaker pro tem. of the House of Representatives.
THEODORE F. DAVIS,
President pro tem. of the Senate.

Passed April 12, 1889.

From the terms of the law, it was evidently intended to provide for the creation of a bureau of geology to which only a portion of the time of the State Geologist should be applied, as the annual appropriation made was much too small to provide the salary of a State Geologist continuously, without making any provisions for office expenses, assistance, etc. It was thought at that time that a few months' work per year would be sufficient to maintain the Survey abreast of geological developments.

The powers and duties of the State Geologist under this act were made so broad and general as to permit carrying on almost any work, so that no new legal provision was thought necessary in connection with re-opening the work of the Survey under the Fourth organization. The sum designated in Section 5 is not made a limiting condition of the law so that the Legislature may appropriate any other amount, at its discretion, for carrying on the work.

Acting under this law, the Legislature has made the following appropriations for geological work:

Designation of Legislature.	Year.	Amount Appropriated.
Seventy-Fourth..............	1900	$2,500 00
Seventy-Fourth..............	1901	$3,500 00
Seventy-Fifth................	1902	$5,000 00
Seventy-Fifth................	1903	$3,000 00
Seventy-Sixth................	1904	$2,800 00
Seventy-Sixth................	1905	$2,900 00
Seventy-Seventh.............	1906	$3,850 00*
Seventy Seventh.............	1907	$5,100 00

*And balance and receipts.

The law providing for the publication and distribution of reports is as follows:

Laws of Ohio, 1902, Vol. 95, p. 593.

(House Bill, 800).

AN ACT

To Provide for the Publication and Distribution of the Reports of the State Geologist.

Section 1. Be it enacted by the General Assembly of the state of Ohio, That whenever the state geologist shall have completed a bulletin upon any of the subjects upon which he is authorized to conduct investigation, he shall notify the state printing commission of this fact, and it shall be the duty of this commission to determine the number of copies which shall be printed, and the grade of paper, the kind of binding, and any other details incident to its proper publication.

Section 2. It shall be the duty of said commission to provide for the publication of said bulletin as soon as possible after the completion of the same. The issue shall consist of a minimum number of three thousand copies.

Of these, one thousand copies, after deducting 200 for the State Library, shall be distributed pro rata among the general assembly.

One thousand shall be distributed free by the state geologist in exchange with other surveys, and with individuals whose services have been used in the collection or preparation of the matter for the bulletins. Of this number not more than four hundred may be distributed during the first year after publication, and not more than fifty in any subsequent year.

One thousand copies shall be set aside for binding along with other bulletins from time to time, when a sufficient number of such bulletins have accumulated to make collectively a volume of from 800 to 1,000 pages. They shall be bound, lettered and numbered, to take their place in the series of volumes already published by the survey.

The distribution of the bound volume of the survey shall be in the hands of the state geologist; but the state library shall receive ten copies, each member of the general assembly one copy, with privilege to draw not to exceed two other copies on application, and public libraries in the state shall be supplied with one copy each. The volumes remaining after these demands have been met, may be distributed among the geological surveys and geological societies of the United States and of foreign countries in exchange for their publications.

Section 3. The board may, at its discretion, order the publication of extra copies in addition to the three thousand already provided for. These extra copies shall be placed in the hands of the state geologist. From these members of the general assembly may, on application, draw up to fifty (50) copies each. Those remaining shall be placed on sale at a price equal to the net cost of printing and binding, which price is to be established by the state supervisor of public printing. The proceeds of such sales shall be accounted for and paid into the state treasury, and the state geologist shall be required by the commission to give suitable bond for the security of the funds thus passing through his hands. The proceeds of such sales shall be credited to the account of the geological survey and shall be used for the prosecution of the further work of the survey without distinction from other funds which the general assembly from time to time appropriates for the survey.

Section 4. The cost of printing, illustrating, electrotyping, binding, et cetera, of said bulletins and said volumes, shall be paid from the general appropriation for state printing.

Section 5. This act shall take effect from and after its passage.

W. S. McKINNON,
Speaker of the House of Representatives.
F. B. ARCHER,
President of the Senate.

Passed May 12, 1902.

THE SURVEY IN ITS RELATIONS TO THE PUBLIC.

The usefulness of the Survey is not limited to the preparation of formal reports in important topics. There is a constant and insistent desire on the part of the people to use it as a technical bureau for free advice in all matters affecting the geology or mineral industries of the State. A very considerable correspondence comes in, increasing rather than decreasing in amount, and asking specific and particular questions on points in local geology.

The volume of this correspondence has made it necessary to adopt a uniform method of dealing with these requests. Not all of them can be granted, but some can and should be answered. There is a certain element of justice in the people demanding such information, from the fact that the geological reports issued in former years were not so distributed as to make them accessible to the average man or community today. The cases commonly covered by correspondence may be classified as follows:

1st. Requests for information covered by previous publications.—This is furnished where the time required for copying the answer is not too large. Where the portion desired cannot be copied, the enquirer is told in what volume and page it occurs and advised how to proceed to get access to a copy of the report.

2d. Requests for identification of minerals and fossils.—This is done, where possible. As a rule, the minerals and fossils are simple and familiar forms, which can be answered at once. In occasional cases, a critical knowledge is required and time for investigation is necessary. Each assistant is expected to co-operate with the State Geologist in answering inquiries concerning his field.

3d. Requests from private individuals for analyses of minerals and ores, and tests to establish their commercial value.—Such requests are frequent. They cannot be granted, however, except in rare instances. Such work should be sent to a commercial chemical laboratory. The position has been taken that the Geological Survey is in no sense a chemical laboratory and testing station, to which the people may turn for free analytical work. Whatever work of this sort is done, is done on the initiative of the Survey and not at the solicitation of an interested party.

The greatest misapprehension in the public mind regarding the Survey is on this point. Requests for State aid in determining the value of private mineral resources, ranging from an assay worth a dollar, up to drilling a test well costing several thousand dollars, represent extreme cases. At present there is no warrant for the Survey making private tests, even where the applicant is entirely willing to pay for the service. In many cases individuals would prefer the report of a State chemist or State geologist to that of any private expert, at equal cost, because of the prestige which such a report would carry. But it is a matter of doubt whether it will ever be the function of the Survey to enter into commercial work of this character; it certainly will not be unless explicit legal provisions for it are made.

4th. Requests from a number of persons representing a diversity of interests, who jointly ask the Survey to examine into and publicly report upon some matter of local public concern.—Such cases are not common. It is not always easy to determine whether such propositions are really actuated by public interest or not. Each case must be judged on its merits. The Survey will often be prevented from taking up such investigations by the lack of available funds, while otherwise the work would be attempted.

The reputed discovery of gold is one of the most prolific sources of such calls for State examination. It usually seems wise and proper to spend a small sum in preventing an unfounded rumor from gaining acceptance in the public mind, before it leads to large losses, and unnecessary excitement. The duty of dispelling illusions of this sort cannot be considered an agreeable part of the work of the Survey, but it is nevertheless of very direct benefit to the people of the State.

BULLETIN No. 4.

THE LIMESTONE RESOURCES AND THE LIME INDUSTRY IN OHIO,

BY

EDWARD ORTON, JR., E. M., and SAMUEL VERNON PEPPEL, B. Sc.

LETTER OF TRANSMITTAL.

PROF. EDWARD ORTON, JR., *State Geologist:*

SIR:—I have the pleasure of handing you, herewith, the text of chapters five and six, on the Uses of Limestone and the Technology of the Lime Industry. My field notes on the occurrence and sampling of the limestones of Ohio, and my notes on the methods of analysis and the tables af analyses of samples, have been turned over to you for use in the preparation of this report, some time since. I wish to thank you for suggestions and assistance rendered in connection with the above work.

Very sincerely yours,
SAMUEL V. PEPPEL.

1538 N. High Street,
Columbus, Ohio.

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ACKNOWLEDGMENTS.

There has been less written on the subject of the lime industry than almost any other branch of chemical technology of equal importance. This fact has made the preparation of this Bulletin, especially chapters five and six, less a work of compilation and more of personal observation than is usually the case. But no personal observation or experience of the representatives of the Survey could possibly have brought to light this mass of important facts in the short time available, had it not been for the coöperation of those already skilled in the business itself.

It is a source of much pleasure to be able to testify to the beautiful spirit shown by the lime manufacturers of Ohio in this connection. They have met the Survey with open arms, have hailed with the greatest interest and enthusiasm the efforts of the Survey to clear up the technology of their problems, and have contributed with an almost unexampled freedom from their records, books and experience.

If this discussion of the technology of the lime industry proves of value, the credit must be given in a large measure to the lime manufacturers who so willingly contributed the results of their years of experience. While each of them responded readily, there were a few among them who had access to plants with special equipment, or who had unusual experience in certain fields, who were thus in a position to furnish more information and make better criticisms than others.

We feel under special obligations to Mr. Chas. Warner, of the Cedar Hollow Lime Co., Wilmington, Delaware. Mr. Warner is not a citizen of Ohio, and could not be appealed to on the grounds of state pride in the work of this Survey, but his interest is broader than state boundaries, and his criticisms and suggestions on all phases of this work have been most helpful.

Mr. Warner's knowledge of the lime industry has been built up by actual contact with the problems involved at his own plants, as well as observation of results at many others. His engineering education has made an admirable foundation for the systematic work which he has done when any new experiment was to be tried.

Among the many Ohio manufacturers whom we wish to thank for assistance, there are some to whom special thanks are due. They were so situated as to be able to give information which was invaluable in the preparation of this report. Among those who gave us the most aid were:

Messrs. F. W. Zorn and A. H. Lauman, of the Standard Lime Co., Gibsonburg, Ohio.

Mr. J. J. Urschel, Mgr. Woodville White Lime Co., Woodville, Ohio.

Mr. W. M. Harsh, of the Kelly Island Lime and Transport Co., Marblehead, Kelly's Island, and Clay Center, Ohio.

Mr. W. S. Sutliff, Mgr. Seneca White Lime Co., Fostoria, Ohio.

Mr H. E. Kendrick, Scioto Lime and Stone Co., Delaware, Ohio.

Mr. Geo. B. Christian, Marion, Ohio.

Mr. J. D. Owen, Owen, Ohio.

Among those to whom we are under obligations for special courtesies shown during the investigations in the quarrying and preparation of limestone are:

Mr. W. O. Taylor, Casparis Stone Co., Columbus, Ohio.

Mr. Sol. M. Wolf, Bellevue Stone Co., Bellevue, Ohio.

The Rucker Stone Co., Greenfield, Ohio.

Mr. F. B. Armstrong, Armstrong Mills, Ohio.

Mr. S. M. Hall, Broken Sword Stone Co., Bucyrus, Ohio.

The Lewis Talbot Stone Co., Dayton, Ohio.

INTRODUCTION.

THE LIMESTONES AND LIME INDUSTRY OF OHIO.

BY EDWARD ORTON, JR.

The lowest element, stratigraphically considered, in the rock floor of Ohio, consists of a great bed of calcareous rock, called the Trenton limestone. Though this deeply buried stratum comes up to daylight in but one point in the state, at Point Pleasant, Clermont county, it has been nevertheless proven to underlie most of the state, by the countless drill holes which have been put down, especially in the western half. Hundreds of these holes have penetrated to or into this well-known bed, which in some portions of the state has been made famous the world over on account of its wonderful resources in natural gas and petroleum. The thickness of the Trenton limestone is a point not yet well established, though it is thought that it has been perforated by the drill in at least one point near Columbus.

Resting on this massive foundation, there follows an orderly series of beds of rock, succeeding each other with a persistent uniformity seldom surpassed in similar areas elsewhere. The gross thickness of these strata is about 3,000 feet, though nowhere in the state is more than 600 feet of it exposed in any natural section. These rocks consist chiefly of limestones in the lower third, though they are intercalated with some thin calcareous shales. In the middle third of the series the limestones give way quite abruptly to alternating beds of shale and sandstones or conglomerates, which occupy about a thousand feet in thickness. In these beds the limestones are practically absent.

The upper third of the rock beds of the state are much less strikingly differentiated from the middle beds than the middle from the lower. The upper third consists of sandstones and shales as the chief lithological factors, but differs from the middle third in the fact that it is interstratified with thin beds of coal, fire clay, iron ore, and limestones, which, though not of much bulk, are of great economic importance. The limestones are not a large element in their upper beds, probably not exceeding 100 or 150 feet in collective thickness of all of the separate strata. They differ greatly from the thick, massive, crystalline light-colored stones which compose the lower third, being dark-colored blue or gray usually, amorphous, and in thin strata of a few feet each.

In these three great divisions, approximately 1,000 feet is known to consist of limestone. This material composes therefore almost a third of the fixed resources upon which the present and future mineral industries of Ohio will depend. In view of these facts, it seems eminently proper to bestow upon the limestones and their products a more searching examination than they have so far received.

Before taking up this discussion mention must be made of the work which has preceded in the earlier organizations of the Survey. The work done consists of three principal contributions.

First: The untangling of the stratigraphical order and geological equivalence of the limestone beds.

Second: The uses of the limestones for the manufacture of quicklime.

Third: The uses of the limestone for the manufacture of hydraulic cements.

The first of these tasks has been done on a scale completely surpassing the two latter. The limestones have not only been classified and studied, for themselves, but also have served, especially in the upper strata of the state, as the most serviceable guides to the unraveling of other problems. This task was largely completed during the work of the Second Geological Survey, but owing to the greater minuteness to which correlation is now carried, and to the great advances in stratigraphical geology which have been made in surrounding states, it has become necessary to repeat this work. The present classification and nomenclature of the Ohio formations is set forth in Bulletin VII.

The article in Volume VI of the Survey by Dr. Edward Orton, discussing the limestones of Ohio from the economic standpoint, especially as regards the manufacture of quicklime, presented the subject as well as the means at hand permitted at that time. As was clearly stated by the author, no laboratory investigations other than chemical analyses were made or attempted, and the data on the technology of lime manufacture were only such as could be gotten from practical men in the business. The literature of the subject, scanty as it now is, was then more scanty and, being almost wholly confined to the German, was not consulted to any extent. The need of revising this work is therefore apparent, especially in view of the numerous improvements and changes which have been brought about in the process of manufacture of quicklime, and in the uses to which lime is now put.

In addition to the ordinary uses of quicklime, a new industry has recently sprung up in the manufacture of bricks from sand and quicklime. The importance of this new structural material has yet to be proved commercially—it is beyond all doubt feasible from the technical standpoint to make it. It has been made the subject of a separate report, as Bulletin V of this series, by Mr. S. V. Peppel, B.Sc. It really falls midway between a quicklime industry and a cement industry, as it uses quicklime as a raw material, but perfects a hydrous silicate bond in the finished product in the process of manufacture.

The third article, on cement, was prepared by Professor N. W. Lord and published in Volume VI. The reasons for again opening up this topic are set forth in full in Bulletins 2 and 3 of the Fourth series, where the work of twenty-four pages of 1888 has been amplified and extended to cover six hundred and forty pages.

The present Bulletin originally had for its object the consideration of the limestone resources of Ohio from the standpoint of the cement industry. It was then thought that the report of 1888 on the quicklime industry was not in urgent need of revision, but that the growth of the cement industry in our midst necessitated a fresh consideration of the lime resources from the new standpoint.

The sampling of the state was largely done with this plan in view. Samples were often so taken as to include shaly strata between limestone beds, which would have been rejected by any lime burner, but which the cement maker would need. Also, samples were taken in general only in districts where it was thought the fitness of the material for cement manufacture was not definitely established, either for or against. The notes made at the time of sampling also were taken chiefly from the same point of fitness for cement.

But as the work progressed, contact with lime manufacturers and dealers made it clear that the scope of the inquiry should be broadened to include the whole subject of lime manufacture. The excellent work of 1888 on the chemical character of the limestones used for quicklime made it seem unnecessary to re-analyze these materials, except in occasional points missed in the former work. But in the technology of the industry, progress had been rapid and in this respect revision was needed.

The work as completed therefore seeks to do three things.

First: To make known the limestone resources of Ohio, from the standpoint of cement manufacture.

Second: To compile and systematize the known facts concerning the limestone resources of Ohio from the standpoint of quicklime manufacture and other uses, and to some small extent to add to this compilation by new studies.

Third: To present as fully as now possible, the present status of the technology of the lime industry.

CHAPTER I.

THE OCCURRENCE, EXTENT AND ECONOMIC CLASSIFICATION OF THE LIMESTONES OF OHIO.

BY EDWARD ORTON, JR., AND S. V. PEPPEL.

The area and distribution of the older and principal limestone beds was worked out by the Survey many years ago. All of the geological maps of the older organizations have clearly delineated the chief areas of limestones, though it has been done as a matter of geology rather than economics.

The map shown on page 00, figure 1, has been copied in all of its essential features from these older maps, but the areas of the limestones of Carboniferous age has been added by the writers.

In many places, the areas of the different formations overlap each other, so that in ravines or in artificial excavations it is possible to open and work stone from two or more horizons at once. Where this situation exists, there is difficulty in the way of adequate rendering on a map. Also, the glacial drift, topographic features and other considerations come in to modify the situation, so that it can by no means be inferred that all places in the shaded or colored areas of the map are suitable for opening quarries, or for manufacturing of cement or lime. The map is meant merely to act as a general guide; to show the areas where each limestone is the topmost or surface formation; to point out the areas in which economic sites may be expected and sought for. The location of the actual site for an industry must take many other considerations into account, so that the occurrence of the stone itself in good quality and quantity is only the fundamental necessity of success. The other conditions will be the prominent ones in determining where, within the area, a plant shall be located.

As has previously been pointed out, the limestone wealth is found geologically in the lower and upper third of the rock system of the state, the vast bulk lying in one compact mass in the lower third, and a relatively small, but not unimportant, quantity being distributed through the upper third.

This division holds not only for geological age, but for geographical location, physical properties, chemical composition, and economic uses as well, so that economically considered, the classification may most easily be made along geographical lines into Eastern or Carboniferous limestones and Western or Pre-carboniferous.

Before discussing the stratigraphical divisions in detail, the use of stratigraphical names should be considered. The quarrymen, lime-burners and lime-users of Ohio are now habituated to the use of the geological names in use in the older surveys, and for that reason it has seemed wise to continue to refer to the formations frequently, if not invariably, by their older title.

On the other hand, the new stratigraphy is unquestionably more accurate, precise and authoritative than any which have preceded it, and it is desirable that it should come into trade use as soon as possible. For that reason, its names, where they differ from the old, are purposely inserted in many places in the text, often as synonyms, as a means of making their meaning known and beginning their use.

The following table, prepared by Professor Charles S. Prosser, and taken from Bulletin 7, will be found convenient in tracing the relationship of old and new names for the formations.

GEOLOGICAL SCALE IN OHIO.

Orton, Vol. vii, 1893.	Prosser, Bull. 7, 1905.
Glacial drift	Alluvium and Glacial.
Upper Barren Coal Measures.	Dunkard formation.
Upper Productive Coal Measures.	Monongahela formation.
Lower Barren Coal Measures.	Conemaugh formation.
Lower Productive Coal Measures.	Allegheny formation.
Conglomerate Group.	Pottsville formation.
Sub-carboniferous limestone.	Maxville limestone.
Logan Group.	Logan formation. Black Hand formation.
Cuyahoga shale.	Cuyahoga formation.
Berea shale.	Sunbury shale.
Berea grit.	Berea grit.
Bedford Shale.	Bedford shale.
Ohio shale. { Cleveland shale. Erie shale. Huron shale.	Ohio shale. { Cleveland shale. Chagrin formation. Huron shale.
Olentangy shale.	Olentangy shale.
Upper Helderberg or Corniferous limestone.	Delaware limestone. Columbus limestone.
Lower Helderberg limestone, or Waterlime.	Monroe formation. { Lucas limestone. Sylvania sandstone. Tymochtee member(?).

GEOLOGICAL SCALE OF OHIO—Concluded.

Orton, Vol. vii, 1893.		Prosser, Bull. 7, 1905.	
Niagara Group.	Hillsboro sandstone. Guelph or Cedarville limestone. Niagara limestone. Niagara shale.	"Niagara Group."	Hillsboro sandstone. Cedarville limestone. Springfield limestone. West Union limestone. Osgood beds.
Clinton limestone.		Clinton limestone, Belfast bed.	
Medina shale.		Saluda bed.	
Hudson River Group.		Richmond formation. Lorraine formation. Eden shale.	
Utica shale, not seen in outcrop.			
Trenton limestone.		Trenton limestone.	

EASTERN GROUP.

The Eastern or Coal Measure groups until recently have received but little consideration from a commercial standpoint. The use in the arts of the limestones of the carboniferous period has been but local in its importance. This localization has been in a large measure due to the rugged topography of the country in which they occur, which retarded ready transportation, even from some of the most favorable localities. Another strong factor in retarding its development has been the nature of the deposits themselves. They are generally rather small in amount; that is, the vertical thickness as a rule is not great, and it is nearly always covered by a thick mass of superincumbent earth, which is cut through by erosion in valleys and ravines. In most cases, these also cut through the limestone as well, exposing it in their walls and sides. Thus the only way to win a large local output will in most places be by underground mining. With very few exceptions all that has been used so far has been exposed by nature; i. e., uncovered by erosion and the weathering agents.

The popular idea that these limestones are all impure and dirty has led most people to pass them by. However, the growth of the portland cement industry and the consequent demand for limestone low in magnesium carbonate, even if it be silicious or argillaceous, has brought about a more vigorous search by both capitalists and scientists, into the quality of all limestone occurring in quantities sufficient for economic winning, especially where located in close proximity to fuel. This search has been productive. It has brought the coal measures into notice as a possible source of limestone. In southeastern Ohio, we find some of our best limestone for the manufacture of portland cement, in close proximity to beds of coal and clay.

These Carboniferous limestones are generally under ten feet in thickness, often only one or two feet being found. They are very hard, dense rocks, even in spite of their solubility in carbonated waters, lasting longer than the sandstones and shales, with which they are intercalated. They generally are blue or dark in color, conchoidal in fracture, fossiliferous, and exceedingly persistent or regular over large areas of country. On this account they have been of infinite service to the stratigraphical geologist, serving as the key to the rocks above and below them. In the largest portion of the coal measure areas, comprising roughly one-third of the state, there are from two to five separate limestone horizons represented in the same territory. These naturally overlap each other, so that an ascent of one hill will often bring three or four limestone horizons to view. But these beds are generally five feet or less in thickness, and as it is not economical to win limestone by underground workings with less than six or eight feet, these areas are excluded from any present importance.

In fact, it has been assumed that the least profitable workable thickness of stone is about eight feet, and only areas of this or greater thickness have been entered on the map, or sampled for analysis. It is not safe to say that the areas of thinner limestones in the coal measure areas will never be of economic value, for conditions change in ways no one can anticipate. These eastern stones are now becoming valuable, due to just such a shift in economic conditions, while heretofore they have been valueless. But the thinner stones, now rejected, apparently suffer from a more serious handicap from their small quantity and difficulty of mining than from either composition or properties or geographical location.

THE WESTERN DEPOSITS.

This division, embracing the greater part of the western half of the state, is a field of great activity, not only in the production of limestone for various purposes, but also for the manufacture of lime and its various by-products. It includes the now famous quarries at Marble Head and Kelley's Island, Marble Cliff and Columbus, Springfield and Greenfield. While the entire area is glaciated, a great deal of the stone lies almost at the surface, being covered by a thin coat of soil only. In many sections erosion has removed the greater portion of the drift originally left by glacial action, so that in almost any part of this area there are limestones at no great depths, making economic winning of the stone possible.

This territory, which has been leveled off by the glacial ice-sheet, whose hollows have been filled and whose hills have been degraded, forms naturally a country suitable for a great population. It is the natural avenue for railroads, canals, and highways. The soil is fertile and well watered, and it has therefore become populous and rich. The imperative needs of this locality for building stone, lime and mortar, would of necessity develop the limestone beds here to a greater extent than in the eastern area, entirely irrespective of the quality of the materials or their extent.

But the advantages have been on the side of the western area, as here the stones are of enormous area, great thickness, easy access and most excellent quality. It is not strange, therefore, that the lime industry of Ohio has secured its first great development in this area.

These western deposits are generally massive, crystalline, light colored stones of remarkable purity. The clay or sand or iron coloring-matter falls below two per cent. in hundreds of places. The composition, however, is generally dolomitic; i. e., the stone is a mixture of carbonate of calcium and carbonate of magnesium, the proportions often becoming those of the mineral, dolomite, itself, which contains 56% of calcium carbonate to 44% of magnesium carbonate. Since dolomite makes a beautiful white lime on calcination, having physical properties similar to but less intense than pure calcium limes, this feature of its composition has not militated against its use in the trades, and, in fact, workmen have learned to prefer it, as it works slower and more mildly than pure calcium lime. Dolomite is as desirable for building material as pure limestone, so that there has been no drawback on this account. In fact, dolomite or dolomitic limestones are as valuable for most of the uses to which limestones may be put, as any other, and only become undesirable in metallurgical or chemical industries, where the base, calcium, is needed in its purest available form. Thus, for furnace flux, a rather low magnesia stone is generally used, while for Portland cement, the magnesia must be as low as possible and never exceed three or four per cent. For such accurate uses, the majority of western stones are at some disadvantages compared to the better quality of coal measure limestones.

It must not be supposed, however, that all of the western stones are dolomitic. Some very pure limestones occur in the Clinton, and low-magnesia stones are not uncommon elsewhere. The exact localities in which they occur will be given in Chapter III.

CHAPTER II.

METHODS EMPLOYED IN SAMPLING AND TESTING LIMESTONES.

BY EDWARD ORTON, JR., AND S. V. PEPPEL.

The analyses of minerals made in the early years of the Survey were probably as skillful and exact as those of recent years have been, but their value stands, nevertheless, on a much lower level. This difference proceeds from the differences in the value of the samples upon which the analytical work was done.

Samples in general are supposed to be so selected, or so prepared, as to truly represent the material from which they are taken. They may be regarded, however, as of two classes; viz: special samples and average samples.

In mineral industries, troubles often arise of which an explanation is absolutely necessary to further or successful work. In searching for the cause of these troubles, it often happens that the rock used contains in limited quantity some single mineral which is the cause of the difficulty, and in this case, the sample may consist of some small quantity, or minute grains scattered here and there through the rock mass. In such a case, careful search and use of concentrating devices and magnifying glasses may be used to procure enough of the suspected substance to positively prove its character. In this case, the sample may be highly unrepresentative of the rock as a whole, but of great importance from the detective standpoint.

On the other hand, the manufacture on a large scale of any of the metallic or non-metallic products like iron, copper, glass, lime, cement, clay wares, etc., requires accurate knowledge of vast quantities of the raw rock-materials, fluxes, fuels, and refractories. Here the problem is the exact reverse of the first case: the average composition and the percentage of fluctuation from a certain mean is the important consideration.

The art of sampling a rock fairly is by no means a simple one. Even when the quantity first taken from the mine, quarry and other exposure is small, and the material is reasonably uniform in composition, it requires either a good mechanical equipment, capable of crushing the whole mass, or a carefully graded series of alternate crushings and grindings by hand, by which a small quantity of homogeneous material representing the whole may finally be obtained.

When the mass to be sampled is large, or where the fluctuation in values between different portions of the mass is great, the difficulty of securing adequate and representative samples increases enormously. As an illustration of this fact, and of the importance which skilled metallurgists, miners, and engineers place upon thorough sampling, the commercial sampling and assaying establishments of Denver, and other mining centers in the West, may be pointed out. These plants, costing many thousands of dollars, have been erected to depend wholly upon custom work for their livelihood. Mineral men and investors looking over properties send large quantities of ore, from a few sacks to several carloads, in order to get the reliability and accuracy which comes from the averaging of large quantities of material. Hence, the elaborate and expensive equipment which shall furnish a small quantity of material truly representing the average composition of the whole is found to be a paying investment.

It follows as a corollary that analyses become correspondingly less in value, in proportion as the sample represents smaller quantities of material, or as the material consists of less homogeneous kinds which do not readily yield an unfluctuating average.

The theory and practice of mineral sampling was not so well developed as it is now, twenty or thirty years ago, when the most of the analytical work of the second Survey was done, and their results are to be accepted with some reserve in consequence.

The samples of limestones, iron-ores, coals, etc., collected in the field were often composed of a single hand-sample, and seldom if ever consisted of more than a few pounds of fragments, chipped off and collected by hand. Experiment has shown that it is difficult, if not impossible, for any person to select a sample without bias, even where not interested in the result, if he is acquainted with the effect of his actions in putting in or rejecting portions. As most of these former samples were selected in this way, the results must naturally be less important.

In limestone sampling, when the product is used almost wholly in industries where uniformity is important, it is quite necessary that the samples represent the deposits fairly, and faithfully reflect the quality of the output, which may be commercially won.

The object aimed at was to procure a sample in such a way as to represent the true composition of a right section of the exposure examined. The core made by a core drill would have been the ideal way of securing this result. That not being available, the next best was adopted.

The following procedure, covering the selection of the sample, was carried out to the fullest extent possible:

First: The sample was cut from the strata in place, rather than to take it from the stock pile. The latter is liable to fluctuate from hour to hour as the products of one stratum or horizon happens to form its surface layer, or be the center of activity from a shot.

Second: The part to be cut was first cleaned well from top to bottom by sweeping with a dust broom.

Third: A canvas sheet nine feet square was spread close under the place selected. The cuttings fell and were collected on the sheet.

Fourth: A gouge or groove was cut from top to bottom of the exposed face of the stone. For this purpose (*a*) a blacksmith hammer of about four pounds weight, (*b*)a blacksmith cold-set or chisel mounted on a handle, (*c*) a few heavy stone cutters, chisels and points were used. By following the edges of cracks, and collecting from different strata at different points in one small area, it is usually possible to get a full cross section of the vein. The size of the cross-cut was usually about three inches wide by one, two or three inches deep. The cross-section must be of substantially the same area from top to bottom.

When on account of the nature of the rock, or its location at great height, requiring climbing and working with but scant footing, this was impossible, the canvass was spread back away from the face of the rock so that a large chunk of the rock could be broken out of a layer, passing clear through it vertically, and from this, a section was dressed off of the desired size, maintaining the same dimensions of section for the whole face as far as possible.

Where narrow strips of shale were sampled with a rock face, as was frequently the case, it was carefully cut out to the same section, holding the canvass right under it so as to lose none of the desired part. Thus the same net results were obtained as in the first procedure.

From the foregoing, it is evident that the samples represented the average composition of the strata for the vertical portion of the face covered by any one sample, including such impurities as may occur with it.

Fifth: All the cuttings were saved on the sheet, rejecting only pieces known to be accidental falls from adjacent points.

Sixth: The total weight of the sample was not less than five pounds nor more than one hundred and fifty, except in special cases.

Seventh: Every sample was marked with a number, inside and outside of the sack in which it is shipped. The inside number consisted of a piece of soft pine, with the number printed or cut or deeply marked with a soft lead pencil, so that no amount of rubbing or dirt could permanently obliterate it. Also, a shipping tag, composed of starched or "filled" muslin, with the name and number written on it, and then rolled up into a tight wad and tied round with its own string made a very good and indestructible inside label, except where moisture got in. The outside label is for the use of freight agents and transfer men. Each bag should be so completely labeled that its identification will be unquestionable, if the outside label is pulled off or becomes undecipherable.

Eighth: When the sample was taken from stock pile, bins, crusher, or from any unusual source, all the circumstances connected with it were noted down.

Ninth: Every detail of the sampling and every observation of the material sampled was noted in the note book, at the time. The cross-section of the strata, any joints, partings, or seams which are persistent, any impurities observed and their distribution, the shipping, both as to character and amount, the depth of the formation above drainage and below drainage when data can be had, etc., were recorded.

Tenth: Duplicate descriptions of each sample taken were sent at first opportunity, so that the office had a copy of the data if the note book were lost or stolen.

Eleventh: The samples were shipped by express or freight, according to circumstances, but in every possible case, the sample sacks were put into the hands of railroad agent before leaving the place, to prevent likelihood of tampering with samples.

This procedure provided for the delivery of the material in sacks at the office of the Survey. The next point consisted in the preparation of the samples for analysis and test. The following procedure was used:

First: All the material shipped was first put through a small crusher of the Blake type, known as the Bosworth crusher. Where the lumps were too large, they were napped down with hand hammers till the crusher could take them. This machine made a powder, most of which would pass an eight mesh screen, but of which the coarsest would barely pass four mesh.

Second: Where the amount crushed was more than thirty pounds, as was usually the case, the material was made up into a conical pile, after repeated shoveling, and was then flattened down to a six-inch layer by spanking with a shovel, and was cut into quarters and separated. One, two or three quarters were taken, so as to make about thirty pounds.

Third: This thirty pounds of material was placed in a ball mill of special construction, made by the P. Hayden Foundry and Machine Company, of Columbus, Ohio, on patterns owned by Mr. W. O. Scheibell. The design of the mill was German. This mill was originally provided with one large ball, about five inches in diameter, two others about three and a half inches, and some six or eight of two inches.

This assortment was supposed to batter to pieces and pulverize stone varying from one and one-half inches down. The mill operated very badly in several respects. It ground very slowly; there was a wide variety in sizes at any stage of the grinding; and worst of all the dust caked or "pasted" against the lining of the mill, so that it could scarcely be gotten off again. This was due to the heavy impact of the large balls. Even heating the stone in advance, and heating the mill during rotation, with gas jets, did not overcome this fault.

The charge of the mill was then changed, using Iceland flint pebbles only, of one and one-half to two inches diameter, and enough of them to occupy about five-eights of the space of the mill. The charge, consisting of dust from the Bosworth crusher, required no heavy balls or impact apparatus: it occupied the interstitial space between balls and enough to cover them an inch or two deep, leaving fully one-fourth of the mill empty. This arrangement worked perfectly, grinding rapidly, without pasting, or contamination, and gave powder of one hundred mesh fineness in about one hour, for a charge of thirty pounds. It was cleaned between charges by putting in a little of the sample next to be ground. To clean the mill thoroughly, sand or burnt fire clay makes an excellent scouring material for both mill and pebbles.

These two machines—i. e., the Bosworth crusher and Scheibell ball mill—make the most effective combination known to the writers for preparing samples of any crude minerals like iron-ore, coal, clay, limestone, sand, ochers, etc., for sampling or laboratory tests, when not more than thirty pounds of fine material is needed, or where the coarse stock does not exceed one hundred and fifty pounds. For larger quantities, machines of larger capacity, but the same relative function, can easily be found. For moderately soft rocks, a dry-pan and ball mill work well together, and for hard rocks, a crusher of the Blake or spindle type, followed by a ball mill, is better.

Fourth: The powder from the ball mill was dumped out into a coarse screen, which retained the pebbles and let the dust fall into a box below. This powder was then carefully quartered down on a sheet of flexible oil-cloth, to about one-half pound sample, which was passed through a one hundred mesh sieve by hand, using an iron hand-mortar to grind any coarse grains still remaining. From this one hundred mesh powder, the sample for analysis was saved in a tightly corked bottle.

Fifth: The large sample, consisting of the ball mill powder, of about one hundred mesh stock, was put away for future use in practical tests if found necessary. These samples were put up in boxes 8 by 8 by 16 inches, made of dry matched pine, and nailed shut.

The testing of the limestones consisted chiefly of the ordinary chemical analysis. The methods used were in no way peculiar, except that owing to the large proportions of clay or shale in many of the samples, they were all fused with sufficient carbonate of soda in the beginning to make them completely soluble. The silica was determined by the method suggested by W. F. Hillebrand, viz: evaporation of the solution of the limestone to dryness on the water bath, filtration removing the bulk of the silica, evaporation of the filtrate to dryness a second time on the water bath, and refiltration in the same filter to remove the additional traces of silica thus separated out. The silica thus obtained was merely weighed by ignition; it was not volatilized with hydrofluoric acid.

The precipitates consisting of the hydrates of iron and aluminum (Al_2O_3, Fe_2O_3) for the determination of the iron and alumina were always dissolved and reprecipitated. When the magnesium carbonate was high, both the calcium oxalate (CaC_2O_4) and the magnesium ammonium phosphate ($Mg_2(NH_4)_2(P_2O_8)$) were dissolved and reprecipitated, in order to get each substance well separated from the other, but when the stone was low in magnesium carbonate. neither precipitate was dissolved. Calcium carbonate was determined by titrating the calcium oxalate (CaC_2O_4) precipitate with a potassium permanganate ($KMnO_4$) solution. one cubic centimeter of which equaled 0.0005 grams of calcium carbonate ($CaCO_3$).

A separate portion was weighed out for the determination of the oxide of iron (Fe_2O_3) and was titrated with a potassium bichromate ($K_2Cr_2O_7$) solution, one cubic centimeter of which was equal to 0.01 grams of iron oxide (Fe_2O_3). Stanmous chloride ($SnCl_2$) was used to reduce the iron. The phosphorus. sulphur and manganese were not determined, although they were sometimes present.

Those interested in methods of analyses for this class of materials should refer to the excellent discussions by Dr. W. F. Hillebrand and others, in *Journal of Society of Chemical Industry* for 1902 and 1903.

CHAPTER III.

THE COMPOSITION OF THE LIMESTONES OF OHIO WITH SPECIAL REFERENCE TO THEIR FITNESS FOR PORTLAND CEMENT MANUFACTURE, CONSIDERED BY COUNTIES.

BY EDWARD ORTON, JR.

This chapter aims to present, in the most convenient shape for public use, all information now available on the composition and properties of the limestone resources of Ohio. The information presented comes from three chief sources.

First: The recent work of Mr. S. V. Peppel, B. Sc., who traveled over a large portion of the state, specifically for this purpose, sampling the limestone, studying its outcrop and situation as regards working, and finally making the chemical analyses of the samples. Mr. Peppel's work on this subject has been much the most complete and thorough that has ever been made by the Geological Survey of Ohio, and would have been presented in the form of a separate report under his name were it not thought best for the public convenience to marshal under one head and in one place all existing information regarding each locality of the state in turn, where limestones exist in workable quantity. As it is, Mr. Peppel's notes constitute the basis and raison d'etre of the chapter.

Second: A study of the Ferriferous limestone of the Hanging Rock district in southern Ohio, and of the Maxville limestone in Hocking, Perry, Muskingum and Licking counties, by the writer, the analyses only being made by Mr. Peppel.

Third: A compilation of the results obtained by the various geologists and chemists who have prepared reports upon the limestones or have occasionally alluded to the limestones in reports primarily upon other subjects. The lack of continuity of the work described from this last source, and the wide divergence in methods of sampling, and methods of analysis, make the data from this source of less value than the other two, but as it supplements it in many places not reached by the recent examination, and as it often confirms the results of the recent work, in districts represented by but one sample, it has been thought highly desirable to use it.

In all cases, the source of the information used has been credited to the person responsible for it.

For convenience in reference, the information has been prepared for each county separately, and arranged alphabetically.

For the benefit of those interested in the stratigraphical features, the data from each geological formation will be found, compiled in tabular form, in a succeeding chapter with remarks on the general character of each limestone formation, as disclosed by the evidence at hand.

Also, for convenience in observing the economic and stratigraphical relationships of outcrops, the map, figure 1 (page 00), has been prepared. It is based on the well-known map of 1888, published to accompany Volume VI., and contains but few new areal features. The limestone areas are indicated by colored shadings of different sorts, and the locations represented by samples taken for this report are indicated by one symbol, and analyses of the earlier reports by another. Constant reference to this map will be necessary to make the descriptions of the resources of each county clear.

ADAMS COUNTY.

This county lies on the edge of the great limestone area of the western half of the state. The western portion of the county is covered by limestone, of the lower and upper Silurian, while on the eastern edge it is covered with the Devonian shales and the sandstones of the Carboniferous. The limestones represented are the Cincinnati or Hudson River group at the bottom, followed by the Niagara group, which make the main surface feature. The Hudson River stone is found in the bottom of the gorges and valleys of much of the county, while the Niagara forms the mass and tops of the hills.

Hudson River Series.—But one locality in the county was sampled. The following is taken from Mr. Peppel's notes: "Sample 85 was taken three miles east of the town of Manchester on the bank of the Ohio river. There is no bluff here, only a shelving bank, with the hills back of it, and the sample was taken layer by layer, measuring the thickness of each. During high water, the top strata represented in this sample would be submerged fifteen to twenty feet. Just northwest of Manchester, samples 83 and 84 were taken from a quarry which is above ordinary high water, but in 1883 was submerged ten feet. A very common section of this group of rocks shows alternate laminæ of limestone and shale, the former varying from three to nine inches and the latter from two to twelve inches. Sometimes the stone is predominant and sometimes the shale."

The analyses follow:

Number of sample.	83	84	85
Description.	Manchester, from top layer down 21 ft.	Manchester, next 12 ft. below sample 83.	Manchester, from water level, Ohio river up 20 ft.
Silica	9.30	10.10	7.86
Alumina	3.04	3.14	2.95
Oxide of iron	1.30	1.30	0.75
Carbonate of calcium	82.50	83.50	85.60
Carbonate of magnesium	1.93	1.51	2.48
Totals	98.07	99.55	99.64

These figures indicate that the stone would make a hot dark gray lime, of the kind unpopular for general mortar use, but very popular in some sections for heavy masonry work. It is distinctly possible for use in the cement industry, if large quantities can be had of similar constitution. The proportions of magnesia are low, and the amounts and ratios of alumina and silica are not unfavorable to Portland cement making. The additional silica and alumina required could undoubtedly be obtained from the fine grained shales which are generally intercalated with the limestones in this district. The fuel for a portland cement industry would have to be imported, but the Ohio river would afford convenient and cheap access to large fields of the best coals.

The Clinton.—Dr. Locke, in 1837, reported the composition of a sample of limestone from Lick Fork, Adams county, which he called the "Flinty Limestone," but which Dr. Edward Orton in the Report of 1869, p. 158, classifies as Clinton, as follows:

	Per cents.
Silica and sand	2.00
Alumina and iron	1.60
Carbonate of lime	93.00
Carbonate of magnesia	3.04
Total	99.64

Not much dependence can be placed upon this last analysis, as nothing is known of the sample; it merely shows that the Clinton is locally highly calciferous and low in magnesia, or such figures could not have been secured.

The Niagara.—Samples were taken at Newport, in the north central part of the county, on the line of the railroad, of which Mr. Peppel says: "The quarry was being operated for crushed stone. In 1901 it shipped about one hundred cars a month. Sample 95 was taken from a stratum resembling the samples taken further south at West Union [which he classifies as in the lower part of the Niagara]. Sample 94 lay above 95 and contained several strata of shale interbedded with the stone."

Number of sample.	94	95
Description.	Newport, from top layer, down 21 ft.	Newport, next 10 ft. below sample 94.
Silica	14.80	16.84
Alumina	5.62	1.78
Oxide of iron	2.34	1.36
Carbonate of calcium	71.40	76.80
Carbonate of magnesium	3.87	2.64
Totals	98.03	99.42

Mr. Peppel's data show clearly that the Newport stone, where he sampled it, is not good for white lime purposes, but that it is distinctly available for cement purposes if its location and other considerations should invite the establishment of an industry there.

At West Union, the county seat, the following samples were secured, and classified by Mr. Peppel, as belonging to the lower part of the Niagara.

"No quarry was in operation, but samples 80 and 81 and 82 were taken out (from an idle quarry). This stone is a light buff or yellow color, resembling a 'free stone' and lies for the most part in heavy beds. In both sample 81 and 82, there is a stratum of four feet thickness. This stone rests on a heavy bed of shale, which probably rests on the Clinton, since at another point in the territory adjacent, the Clinton was observed to be below the 'freestone' layers.

"A sample (number 96) was also taken out at Peebles, which probably comes in near to and beyond the bottom of the stratum represented in sample 95. It was a reddish yellow, weathering to a yellowish brown stone, in beds making a total thickness of 12 feet or more."

Number of sample.	80	81	82	96
Description.	West Union, from top layer down 4 feet 6 inches.	West Union, next 6 ft. below sample 80.	West Union, next 8 ft. below sample 81.	Peebles, from top down 12 ft.
Silica	4.46	17.80	24.56	14.32
Alumina	1.83	2.39	3.06	1.70
Oxide of iron	1.91	1.87	2.80	2.30
Carbonate of calcium	51.90	44.00	39.50	56.20
Carbonate of magnesium	40.45	33.78	29.30	24.94
Totals	100.55	99.84	99.22	99.46

The West Union stone was analyzed in 1869 by Wormley, and published in an article on the geology of Montgomery county by Dr. Edward Orton, Rep. 1869, p. 159, under the title of "Cliff" limestone, with the remark that the analysis confirms the statement of Dr. Locke, that the rock in question would yield hydraulic cement.

	Per cents
Silica and sand	18.80
Alumina and iron	2.20
Carbonate of lime	42.80
Carbonate of magnesia	34.79
Total	98.59

Other Horizons.—Mr. Peppel sampled another calcareous deposit about two miles from Peebles in northern Adams county, a short distance from the railroad, which he characterizes by the name of "marl," as that is the term used locally for its designation. This so-called "marl" does not resemble the marls of other sections of the state, either in physical or chemical properties. It is almost white in color, and freshly fractured surfaces have a luster suggesting the vitreous or glassy. The fracture is conchoidal, showing little or no evidence of bedding, and the stone is not quite so hard as crystalline limestone. When exposed to weathering agencies, it breaks down first into irregular cube-like masses. These finally degenerate into a coarse rather granular powder. The deposits are not apparently continuous, but seem to be pockets and are probably of fresh-water origin.

Number of sample.	97	98
Description.	Peebles, from top down 12 ft. 6 in.	Peebles, next 5 ft. 6 in. below sample 97.
Silica	0.42	0.26
Alumina	0.54	0.50
Oxide of iron	trace	trace
Carbonate of calcium	55.90	55.90
Carbonate of magnesium	43.94	43.94
Totals	100.80	100.60

The thickness of the bed, and its highly dolomitic character, makes it remarkable, if it really is a marl, or soft fresh-water deposit of recent age. Its composition in other respects does not correspond to the hard limestone rocks of that district. Its value would depend on its physical condition, and quantity. Whatever these marls may be, they are of little industrial importance, since their extent is not very great, and in some cases to uncover any large amount would require excessive stripping. For lime, it would probably crack up and give only a coarsely powdered quicklime, difficult to handle.

ALLEN COUNTY.

In Allen county the Lucas limestone, the Water-Lime or lower Helderberg of the earlier classifications, is the first solid bed reached by excavation, except in the southeastern corner, where a small area of the underlying Niagara comes to the surface. Both of these formations are strongly dolomitic in character, and in other parts of the state both are widely used in the manufacture of the finest white lime. The industry does not flourish in Allen county at present, the stone finding use principally for building purposes or concrete and ballast material.

Lucas Limestone.—The stone was sampled at Lima and Bluffton. The Lima sample was from the quarry of Mrs. C. L. Sanford. It was a thin-bedded gray-brown stone, used at present for crushed stone. The Bluffton sample is a cross section of the rocks shown in the L. T. Sidall quarry. It is a thin and unevenly bedded stone, of brown color. The stripping is from three to four feet of glacial drift and residual soil. The stone is all crushed at present, no lime being burnt. Other quarries in the vicinity are producing considerable building stone.

Mr. Peppel's analyses are as follows:

Number of sample.	27	28
Description.	Lima. From top down 26 ft.	Buffton, from top down 12 ft.
Silica	1.40	2.70
Alumina	0.88	1.32
Oxide of iron	trace	trace
Carbonate of calcium	54.25	53.00
Carbonate of magnesium	43.36	42.80
Totals	99.89	99.82

The same stratum was formerly extensively burned for lime in Bath township, by G. W. Fetters, the product being hauled into Lima for use in mortar and in strawboard works. This industry has probably been crowded to the wall by the limes of Sandusky and other points where the burning is done on a very large scale and with the best appliances, and for the shipment of which favorable rates are made.

This quarry was sampled in 1887 by Dr. Edward Orton, from the ten feet which was used for lime burning, and analyzed by N. W. Lord:

	Per cents.
Silicious matter	1.18
Alumina and oxide of iron	0.14
Carbonate of lime	53.69
Carbonate of magnesia	45.00
Total	100.01

Dr. Orton says: "These figures show the Fetters lime to have the ordinary excellence of the formation from which it is derived. The upper beds of the series are, in this vicinity, hard, blue, and impure, and consequently are not used at all for lime manufacture. By proper selection, hydraulic limes and natural cements would both be obtained from these sources, but it is not probable that the latter could be manufactured at a profit as against the great advantage of Louisville and other points in this regard, as well as the strong tendency toward the use of portland cements instead."

ATHENS COUNTY.

Athens county, lying wholly in the coal measures, possesses only the characteristic limestones of that group of rocks. In the northwestern and western portions of the county, the upper members of the Allegheny formation, the lower and middle Kittanning and lower Freeport coals are above drainage, but in central and eastern portions of the county, the strata lie in the Conemaugh and Monongahela formations. It is in these two groups that the limestone wealth of the county is found. In the Allegheny the only limestones found are usually thin and economically valueless strata on the horizon of the Freeport coals.

Freeport Limestone.—A vein, tentatively referred to this horizon by Mr. Peppel, reaches a sufficient thickness to quarry for road metal in Lee township; the stratum is here about one-half flint. The sample (No. 142) was taken at Albany, by Mr. Peppel, from a vein seven feet six inches thick. He states that it lay one hundred feet below the Crinoidal limestone. If by the latter is meant the Ames limestone, this would probably classify the sample as Cambridge. The latter formation is often flinty, especially where it thickens up locally, as is the case here. Whether Cambridge or Freeport, the stone probably has no great economic future. Mr. Peppel's analysis follows:

	Per cents.
Silica	50.30
Alumina	5.46
Oxide of iron	1.20
Carbonate of calcium	40.91
Carbonate of magnesium	1.36
Total	99.23

This stone would be of possible interest to cement makers as a means of getting amorphous silica into their high alumina mixtures, without objectionable accompaniments. It could only be used as a corrective for some other stone, but it seems possible for it to be very useful for this purpose.

The area available for economic winning is not very large. It is, however, located close to the railroad and could easily be transported for the purpose of correcting the composition of cement mixtures. It might prove of value should the stone from Ames township, about twelve to fifteen miles north of it, be developed.

Pittsburgh Limestone.—The limestone found under the Pittsburgh or No. 8 coal is rarely of any economic value, being usually too thin to permit working. One place, in Ames township, was found by Mr. Peppel, where the stone thickened up to fourteen feet six inches. It lies in this locality from two to twenty-five feet below the Pittsburg coal. A sample, No. 141, was taken with the following results (Peppel):.

	Per cents.
Silica	4.62
Alumina	1.44
Oxide of iron	1.00
Carbonate of calcium	90.90
Carbonate of magnesium	1.60
Total	99.56

This stone, if its thickness and composition remain as shown in the above test, would be of interest to portland cement makers. Its low magnesia, high lime and good silica-alumina ratio are all favorable, and the recorded thickness is good. Occurring in a district where coal is abundant, such a mineral should have an industrial future. It would not make a desirable white lime for mortar.

This stone occurs near the top of a series of very narrow ridges on the west side of a little valley, so there is no very large extent of the deposit available, yet there is no doubt that sufficient of this stone can be found in this locality to supply a cement plant for many years. It is, however, five to six miles distant from present transportation facilities. None was found on the east side of the valley mentioned, and there is probably none there, as the hills are of insufficient height to carry it.

The limestones lying over the Pittsburg coal, and under the Meigs Creek or No. 9 coal are included in the same group as the stone found immediately beneath it. This grouping is not intended to have any stratigraphical significance, but is merely economic. Those above the Pittsburg coal, Mr. Peppel divides into five sub-groups—B, C, D, E and F, according to their distance above the datum or coal vein.

In Athens county, the following localities were found to have these limestones developed in workable thickness:

Sample 137 came from the McGraw farm, Berne township, at the west end of the Rues tunnel on an abandoned railroad, near Stewart junction, one and one-half miles west of Big Run station. The thickness of the section sampled was fourteen feet. The limestone layers varied from six inches to three feet in thickness. The lower half was heavier in bedding, and free from shale streaks. The upper half contained one four-inch, one three-inch, and one six-inch shale streak. The sample included several layers of buff stone, but was in the main blue and gray. The sample was thought to come from about fifty-five to seventy feet above No. 8 coal, but Mr. Peppel found the evidence on this point very meager.

Sample 136 was taken on the John Parmeter farm, on Watts run, two and one-half miles south of Amesville, and three-fourths mile west of the railroad. The section sampled was:

	Feet.	Inches.
Limestone	6	0
Shale and nodular limestone	2	0
Limestone	0	6
Shale and nodular limestone	1	6
Limestone	1	0
Shale	0	6
Limestone	1	0
Shale	0	6
Total	13	0
Shale to bed of run	15	0

The position of the coal was not observed at this point, but the stone was on its physical character classed as E, seventy to eighty feet above the Pittsburg and just under the Meigs Creek or No. 9 coal.

Sample 143 was taken on Walter Bayard's farm, from an old railroad cut, one-fourth mile east of the present depot at Canaansville, and close to the B. & O. S.-W. railroad. The section sampled was as follows:

	Feet.	Inches.
Shale	6	0
Limestone	1	6
Limestone with two three-inch and one six-inch shale streaks	14	6

Interval to railroad level, seventy-five to eighty-five feet. The roof was sandstone and shale.

The fourteen feet six inches of stone was composed of stone strata of irregular thickness, the shale streaks thinning and thickening as the stone fluctuated.

The samples, analyses, and notes are all by Mr. Peppel.

Number of sample.	137	136	143
Description.	Big Run, 14 ft. in thickness.	Amesville, 13 ft. in thickness.	Canaansville, 14½ ft. in thickness.
Silica	14.88	22.90	14.50
Alumina	5.41	8.17	4.56
Oxide of iron	1.81	2.07	1.40
Carbonate of calcium	67.45	62.29	76.78
Carbonate of magnesium	9.15	2.69	1.21
Total	98.70	98.12	98.45

The future value of these stones lies chiefly in the field of cement manufacture, apparently. Nos. 136 and 143 are both capable of taking place in a portland cement mixture. The bed represented by 143 could only be won in a large way by mining. No. 147 is ruled out from the portland cement group by its magnesia, but might possibly be used for a roman cement by discarding the small amount of shale which accompanies it. The presence of the Pittsburg and Meigs Creek coals with the stones makes a factor in the problem.

BELMONT COUNTY.

This county lies wholly in the coal measures, and its surface strata belong entirely to the upper portion of the Conemaugh, the Monongahela, and the Dunkard formations. The No. 8 or Pittsburg coal is low in the valleys on the western edge of the county, often below drainage, and in the hills on the Ohio river at Bellaire and Powhatan is above drainage. The rise in drainage to the north and west is slightly more rapid than the rise in the coal.

The limestone wealth of the district is comprised in the numerous and somewhat irregular strata that occur from below the Pittsburg to above the Meigs Creek coal veins. These stones have been burned for a hydraulic cement of the roman type for many years, but at this time nothing is being done with them.

Dr. Newberry in 1870 referred in strong terms to the use of these stones at Barnesville, where they were being burned and ground for cement by T. C. Parker. Wormley, in 1870, made analyses of a number of stones from this district. Finally N. W. Lord, in 1888, referred again to the Parker cement and gave fresh analyses made by himself, of the material produced at that time at the Bellaire works. The data are here reproduced for convenience in reference.

Sample number.	1	2	3	4	5	6	7	8
Silica	8.47	29.80	30.60	24.00	17.40	8.60	31.20	16.41
Alumina	4.85	13.80	13.00	7.00	6.20	4.90	6.60	5.44
Oxide of iron	3.10	.....	.....	.....	.....	.....	.....	3.38
Carbonate of calcium	72.10	41.20	40.60	37.90	51.80	80.70	37.80	46.52
Carbonate of magnesium	11.15	15.36	15.18	30.47	23.94	5.69	23.89	26.40
Moisture and loss	0.33	.....	.....	.....	.....	.....	.....	.....
Totals	100.00	100.16	99.38	99.37	99.34	99.89	99.49	98.15

1. Parker's cement stone, 1870, analyzed by Dr. P. Schweitzer.
2. Parker's cement stone, 1870, analyzed by Dr. T. G. Wormley.
3. Cement limestone near Wornock's station, B. & O. R. R., Wormley.
4. Wegee cement rock, 18 inches from bottom, Wormley.
5. Wegee cement rock, near top of vein, Wormley.
6. Limestone, 18 inches above cement rock, Wormley.
7. J. F. Hutchinson's cement limestone, Putterey, Wormley.
8. Bellaire cement limestone, 1887, N. W. Lord.

The references serve to show that the impure silicious and magnesian limestones of this county have had quite an industrial development in the past. They also show that the same stones, tested by the different writers, were very irregular in composition, and by inference, gross differences in composition of the roman cements made from them were not considered prejudicial, as in the case of numbers 1 and 2. They also show that different strata varied greatly from high magnesian to low magnesian, as in numbers 4 and 6.

This field was carefully examined by S. V. Peppel in 1902–03, whose samples materially add to our exact knowledge of the facts in this district.

Beginning on the west, the limestone was first sampled on the farm of Mrs. Kate Maldine, one mile north of Barnesville. The geological section here shown was as follows:

	Feet.	Inches.
Meigs Creek coal (No. 9)	0	0
Sandstone and shale	23 to 25	0
Coal	1	10
Hard blue or gray limestone, carrying small amount of shale	7	6
Buff or gray limestone, locally known as "cement stone"	6	0
Interval to Pittsburgh coal	55–60	0

The buff or six-foot stratum was sampled as number 171. The upper, or blue-gray stratum, carrying shale was sampled as number 170.

Another sample was secured on the National road, four miles north of Barnesville, near Henrysburg, from the farm of W. G. Major. A coal blossom was opened about twenty-five feet under this point, which was considered at the time to be No. 8, but which Mr. Peppel subsequently concluded to be the twenty-two inch vein shown in the Barnesville section. The section was as follows:

		Feet.	Inches.
	Sandstone	..	..
	Limestone	1	0
	Sandstone	1	0
	Shale	2	0
Sample 172	Limestone, light brown in color, solid, in even beds	7	0
	Interval	25	0
	Coal blossom, twenty-two inch vein of Barnesville.		

The results of the analyses by Mr. Peppel are:

Number of sample.	171	170	172
Description.	Barnesville, "Cement stone," 6 ft. thick.	Barnesville, 7 ft 6 in. lying just above 171.	Henrysburg, 7 ft. above on the horison of the Meigs creek coal.
Silica	16.10	14.06	3.14
Alumina	5.74	4.33	0.74
Oxide of iron	2.28	1.13	0.90
Carbonate of calcium	51.25	66.31	92.48
Carbonate of magnesium	23.02	12.71	1.84
Totals	98.39	98.54	99.10

Sample No. 172 seems to be anomalous. Its purity and low magnesia contents are not duplicated in any other analysis from this county. It would make an admirable portland cement material, if it is uniform as above, and if enough can be found. At the location sampled, the stone would have to be won by open quarrying and for the uncovering of any great quantity the stripping would be so excessive as to prohibit large development. If this same stratum maintains its thickness and composition over any very wide area, there are no doubt locations to the north where it could be mined.

The other results confirm those of the earlier workers as to the general character of the stone used for roman cement. It is limited to the productions of the roman cements and would not be available as a constituent for portland cement, nor for white lime.

At Armstrong's Mills, in Washington township, on the line of the B. Z. & C. R. R., a particularly favorable geological section is exposed and this was elaborately sampled by Mr. Peppel as follows:

		Feet.	Inches.
	Sandstone	..	..
	Shale interstratified with about one-fourth limestone	47	0
	Limestone (roof)	3	0
Sample 162	Shale, hard and calcareous	2	6
	Blue limestone, not very hard	1	0
	Blue limestone, hard	3	0
Sample 163	Shale	1	0
	Limestone, impure and shaly	4	0
	Blue limestone, hard	5	0
	Shale	0	6
	Blue limestone	1	0
	Shale	0	9
	Limestone	1	0
	Green shale	4	0
Sample 168	Gray limestone	3	0
	Shale	0	6
	Buff limestone	4	0
	Brown limestone, shaly	1	0
	Dark gray limestone	1	0
	Blue shale	1	0
	Gray limestone	2	6
Sample 164	Blue limestone	1	6
	Dirty limestone, hard, but laminated	0	6
	Light brown limestone	2	0
	Brown limestone	3	0
	Blue limestone	6	0
	Dark brown slaty limestone	1	0
	Soft slate	1	0
	Coal, Meigs Creek	4	0
	Interval, containing shale with a little sandstone	23	0
	Limestone (roof)	2	0
Sample 165	Limestone, hard blue, in 4 courses	8	0
Sample 166	Hard fine-grained shale, bleaching to a light color on outcrop Hard fine-grained shale, very dark color	5	0
Sample 167	Blue limestone	4	0
	Shale, brown in part	1	0
	Blue limestone	3	6

Thus it is seen that for about fifty feet above and below the Meigs Creek coal, the strata are predominatingly calcareous. Whether the grouping of the members differently would have made a materially different or better showing, for the characters of the materials, is of course only open to conjecture.

Mr. Peppel's analyses follow:

Number of sample.	162	163	168	164	165	166	167
Description.	6 ft. 6 in., 50 ft. above the Meigs creek coal.	13 ft. 3 in. below 162.	13 ft. below 163, interval of 4 ft. not sampled.	17 ft., resting on the Meigs creek coal.	8 ft., 25 ft. below the Meigs creek coal.	5 ft., shale below 165.	8 ft. 6 in., below 166.
Silica	29.16	25.88	17.10	25.46	10.20	26.10	17.02
Alumina	8.43	7.06	4.90	10.11	2.41	9.64	4.56
Oxide of iron	2.69	1.84	1.24	1.25	1.13	1.30	1.74
Carbonate of calcium	44.23	47.70	58.93	45.40	73.57	45.70	59.78
Carbonate of magnesium	13.56	15.84	16.87	15.53	12.19	15.45	15.98
Totals	98.07	98.32	99.04	97.75	99.50	98.19	99.08

The proportions of lime and magnesia vs. silica and alumina fluctuate reciprocally with the inclusion of more or less of the shaly strata, but in the case of sample 165, which contains no shale, the character of the limestone is clearly shown to have no field of usefulness in either white lime or portland cement manufacture, though it might be of value for agricultural purposes. That it would be used for the roman or natural cement is beyond doubt. Also other sections in the locality can undoubtedly be found, in which limestone of good quality for roman cements can be obtained, by exclusion of the shale intercalated with the stone beds. The introduction of the roman cement industry into this section is, however, a question of economics rather than of mineral resources.

The Pittsburg coal is getting deeper as one goes towards the southeast, and these limestone formations, especially the lower numbers, get under cover shortly below the south line of Belmont county. Sample number 159 was taken at a point two miles west of Powhatan, on the south side of Captina creek, near a road bridge over the creek, and 158 a mile further south. These samples were selected to represent the southern edge of the field.

The section was as follows:

		Feet.	Inches.
	Limestone over the Meigs creek coal	..	..
	Meigs creek coal	..	..
Sample 159	Hard blue limestone in heavy beds, lower two feet of which is dark in color, tending to become nodular	8	0
	Interval, not seen	15-20	..
	Limestone, roof (at least)	2	0
Sample 158	Light buff limestone, soft	2	6
	Hard blue limestone	1	0
	Nodular limestone and shale	0	6
	Hard blue limestone	2	6
	Buff limestone	1	6
	Curly, impure, dark colored limestone	2	0
	Interval to Pittsburgh coal	40-50	..

Mr. Peppel's analyses follow:

Number of sample.	159	158
Description.	Powhatan. 8 ft., just under Meigs creek coal.	Powhatan. 10 ft. about 20 ft. below 159.
Silica	14.94	14.40
Alumina	4.57	4.73
Oxide of iron	1.95	2.65
Carbonate of calcium	70.15	59.40
Carbonate of magnesium	8.22	18.39
Totals	99.83	99.57

The stone has practically the same characteristics here as in preceding samples.

Bellaire, once the seat of a small roman cement industry, was next examined.

The section represented there is as follows:

		Feet.	Inches.
	Sandstone	..	..
	Sandy shale	5	8
	Blue limestone	1	0
	Green sandstone, slightly laminated	5	0
	Limestone and shale	12–15	..
	Sandy shale, with nodular limestone	4	0
	Green shale	0	6
	Hard, dirty earthy limestone	5	0
	Brownish gray limestone	1	0
	Green shale and limestone (same as used for sample 156 at Glencoe)	12	0
	Green shale	4	0
	Interval, mostly limestone, sufficient for roof purposes	5–7	..
Sample 155	Brittle light colored stone, degenerating into shale at a few points	6	0
	Green and yellow shale	2	0
	Gray limestone	3	0
	Gray shale	1	0
	Limestone	2	0
	Meigs creek coal	..	..
	Sandstone, gray and laminated, uneven in bedding	15–16	0
	Coal	1	0
Sample 160	Shale, friable	0	6
	Heavy blue limestone, bleaching white	7	6
Sample 161	Limestone, blue	4	0
	Shale	0	6
	Limestone	2	6
	Shale	1	0
	Impure limestone	2	0
	Interval unseen. Coal in bed of stream. Interval to No. 8 coal	43–45	..

The above section was measured and the samples were taken about one mile west of Bellaire on Pinch run. Two additional samples were selected one mile east of Glencoe and one-half mile south of the B. & O. R. R., where the following section was measured:

		Feet.	Inches.
	Roof, green sandstone	2	0
Sample 156	Green shale	1	6
	Limestone, in heavy beds, varying in color from gray blue to black	8	0
	Green shale	4	0
	Limestone and shale	30–35	..
	Coal, Meigs creek	..	..
	Interval was not measured	..	..
	Roof, good limestone	..	..
Sample 157	Light buff limestone in heavy beds	7	0
	Blue limestone	0	6
	Yellow limestone	0	9
	Hard blue limestone	0	4½
	Yellow limestone	0	4½
	Hard blue limestone	1	0
	Interval, unknown	..	..
	Blue limestone, hard	5–6	..
	Interval, unknown	..	..
	No. 8 coal	..	..

The results of the analyses by Mr. Peppel are given below:

Number of sample.	155	160	161	156	157
Description.	Bellaire, 14 ft. just above Meigs creek coal.	Bellaire, 8 ft., 20 ft. under Meigs creek coal.	Bellaire, 7 ft. under No. 160.	Glencoe, 12 ft. above the Meigs creek coal.	Glencoe, 10 ft. below the Meigs creek coal.
Silica	25.12	9.86	12.36	33.68	11.20
Alumina	9.48	2.84	3.92	10.06	3.46
Oxide of iron	1.60	0.60	1.24	2.08	0.80
Carbonate of calcium	36.35	76.10	70.90	41.20	68.00
Carbonate of magnesium	25.18	11.00	10.75	10.19	15.75
Totals	97.73	100.40	99.17	97.21	99.21

Here, again, the samples show a composition in every way comparable to those from the preceding localities.

Proceeding to the northern part of the county, the following section was measured on Glen's run, one and one-half miles west of Burlington (Don P. O.), and samples were taken at points indicated in the section.

		Feet.	Inches.
	Limestone, similar to sample 155	..	..
	Coal blossom	..	..
	Shale and sandstone	20–25	..
	Blue limestone (roof)	1	6
Sample 174	Brownish blue limestone, hard	2	0
	Yellow limestone, weathering to an earthy mass	2	0
	Brown shale	0	3
	Yellow limestone, same as above	2	9
	Shale	6	0
	Solid blue limestone (roof)	1	6
Sample 173	Gray shale	2	0
	Hard blue limestone	3	0
	Shale	1	0
	Hard blue limestone	4	0
	Shale	0	6
	Hard blue limestone	3	0
	Shale about	6	0
	Limestone (roof)	1	6
Sample 175	Hard blue gray limestone	6	0
	Hard gray limestone	2	0
	Soft white limestone	1	0
	Dirty blue limestone, hard	1	0
	Interval to No. 8 Coal	6–8	..

The analyses are as follows:

Number of sample.	174	173	175
Description.	Glens Run, 7 ft., 8 ft. above sample 173.	Glens Run, 13 ft. 6 in., 8 ft. above sample 175.	Glens Run, 10 ft.; 8 ft. above No. 8 coal.
Silica	8.74	19.68	13.60
Alumina	3.30	6.77	3.69
Oxide of iron	1.30	1.63	1.95
Carbonate of calcium	70.40	61.50	69.60
Carbonate of magnesium	15.30	9.00	10.90
Totals	99.04	98.58	99.74

Again, the character of the Belmont county limestones is demonstrated to be inferior for all but the one purpose for which they have thus far found adaptation.

These results, while they do not prove that occasional patches of pure high-calcium, low-magnesia limestones may not be found, and, in fact, offer an illustration of this in sample 172, still strongly indicate that closer sampling of the strata will bring out no important differences. The samples represent a wide stratigraphical and geographical range, but are nearly uniform in the presence of much magnesia and of shaly strata which would always keep the silica and alumina high.

The future of this district then seems to hang on the discovery and working of occasional patches like sample 172 or the expansion of the old natural or roman cement industry now defunct.

It is very improbable that the roman cement industry in this section will receive any development in the near future. At best it could be of but local importance, since in the mining of the raw material, the manufacturer would be at a considerable disadvantage over roman cement manufacturers elsewhere. It would be necessary to mine comparatively thin veins of material, which are somewhat erratic in their composition. Aside from this, it would almost invariably be necessary to sort out some shale from between the limestone beds, or to move shale lying below or above the stone, in the exigencies of mining the rock. The greatest value of the Belmont county limestones will lie in the development of the crushed stone industry.

BROWN COUNTY.

This county is covered by the limestones of the Hudson River group, almost exclusively. In the eastern edge, the overlying Clinton and

Niagara cover a small territory. The county has never been active in the use or manufacture of lime, and reference to the older surveys brings no record of limestone analyses having been made.

Mr. Peppel visited the district and took a series of samples about one mile west of Georgetown, on the west bank of the White Oak creek, from a bluff known as Bald Point, on lands owned by V. K. Thompson and T. J. Andrews. The total face of the cliff comprised in his samples is one hundred and forty-five feet six inches. Underneath this, he reports that there lies from eighty to one hundred feet of shale, nearly free from limestone streaks, while beneath this again, the limestone streaks become more prominent down to the bed of the creek.

His results are as follows:

Number of sample.	86	87	88	89	90
Description.	From top down 16 ft. 6 in.	Next 23 ft. below sample 86.	Next 50 ft. below sample 87.	Next 26 ft. below sample 88.	Next 30 ft. below sample 89.
Silica	13.20	32.80	32.34	31.60	45.36
Alumina	4.46	9.12	8.69	10.97	15.24
Oxide of iron	1.30	2.30	2.45	2.85	3.90
Carbonate of calcium	78.05	49.65	50.00	47.25	26.25
Carbonate of magnesium	2.36	4.12	4.15	5.00	5.06
Totals	99.37	97.99	97.63	97.67	95.81

The first sample, only, No. 186, has any interest as a source of lime. It has a composition very nearly correct for the manufacture of portland cement as it is. It is quite probable that other strata could be picked out of the face sampled, rejecting the shaly portions, whose proportion of lime would be equal to 86. Altogether, the outlook is not encouraging for the establishment of a lime industry in this vicinity, although a considerable area of stone, similar to sample 86 with very little stripping could be made available for cement industry by the laying of about one mile of railroad.

It is worthy of note here that with the increase in the proportion of shale, there is a corresponding increase in magnesia. suggesting that the stone itself is practically free from magnesia. The stone, provided all shale was discarded, would make a very hot, quick-setting, dark-gray lime, suitable for masonry and agricultural purposes.

BUTLER COUNTY.

The Hudson River group is everywhere the surface rock of this county. This formation supports no lime industries at present, because other districts possessing a stone which makes a beautiful white lime have driven the gray local product from the field. Its use, for some time to come at least, seems to depend on finding other fields than the mortar industry. Two districts were sampled by Mr. Peppel, with the following results.

The first set of samples was taken at Excello, from a small exposure at the bottom of a high hill, just east of the C. H. & D. R. R., There is more of the same formation in the hill above.

Number of sample.	66	65	
Description.	From top down 10½ ft.	Next 10½ ft. below sample 66.	Mean.
Silica	28.94	31.80	30.37
Alumina	10.00	10.95	10.475
Oxide of iron	2.90	3.25	3.075
Carbonate of calcium	52.95	48.40	50.675
Carbonate of magnesium	2.65	3.25	2.95
Totals	97.49	97.65	97.545

This stone is seen to be very impure in both samples, and offers no special inducement for use.

The second set of samples was taken from a quarry owned and operated by Daniel Pabst, at Hamilton. The stripping runs from one to six feet. The fifty feet interval below sample down to the river is composed almost entirely of shale.

Number of sample.	58	59	57	56	55	
Description.	From top layer, down 11 ft.	Next 15 ft. below sample No. 58.	Next 15 ft. below sample No. 59.	Next 8 ft. 6 in. below sample No. 57.	Next 11 ft. below sample No. 56.	Mean.
Silica	36.00	29.96	33.86	26.10	34.80	32.38
Alumina	12.36	9.55	11.56	8.44	11.62	10.77
Oxide of iron	3.70	3.05	3.50	2.30	2.80	3.12
Carbonate of calcium	41.60	49.80	44.00	56.80	42.50	46.52
Carbonate of magnesium	3.57	3.06	3.72	3.58	4.72	3.69
Totals	97.23	95.42	96.64	97.22	96.44	96.48

This material, as it stands, is much too high in clay matter to be useful for lime purposes, or for cement making. It probably contains a number of strata of shale which could be excluded in quarrying at small increased expense, and which could bring the lime content to a workable pass. The fact that the magnesia remains fairly low indicates that it would remain low, and possibly be lowered, if the shale strata were excluded, and only the limestones included in the test.

CLARK COUNTY.

Clark county is covered with limestone strata wherever the solid rock is relieved of its glacial covering. There are a variety of stratigraphical formations represented, the Hudson River group appearing in the southwestern corner, in the deeper valleys, while the Waterlime appears in the northeastern corner. The bulk of the territory is covered with Niagara formation.

This district has long been the center of a lime and stone business, an industry which is still flourishing. The older reports of the Survey have supplied such complete statements of the uniform and excellent quality of the stone for white lime purposes that their testimony must needs be accepted. The number and uniformity of the analyses cited to prove this view bring assurance of a stone of high quality. No matter how differently the sampling was conducted from present methods, if the material had been irregular, some one or other of the samples would have shown the fact. Accordingly, no new sampling was done in the vicinity of Springfield, which is the chief center of the lime and stone industry. For reference, the following tables of analyses made by Wormley in 1869 and 1870, and Lord in 1886, are given:

Analyses of Springfield Limestones by Dr. Wormley (1869 and 1870).

Description of sample.	Thompson's quarry.	Moore's quarry.	Frey's quarry, bottom rock.	Frey's quarry, middle rock.	Frey's quarry, top rock.	Sintz quarry, building stone.	Petticrew's quarries, middle bed.	Petticrew's quarries, top bed.	Holcomb's quarries.
Silica or silicious matter..	8.26	4.80	3.10	0.10	1.50	7.60	1.30	1.40	0.10
Alumina and iron	0.70		0.30	0.20	1.00	3.10	1.80	2.70	1.70
Carbonate of calcium.....	50.90	46.40	53.70	54.70	54.70	49.70	55.40	53.90	55.10
Carbonate of magnesium..	39.77	47.53	43.13	44.93	42.37	39.20	41.48	41.90	43.05
Totals	99.63	98.83	100.23	99.93	99.57	99.60	99.98	99.90	99.95

Analyses of Springfield Limestones by N. W. Lord (1886).

Description of sample.	Average of a number of analyses.	Moore's quarry, average sample.	Frey's quarry, average sample.	McCarty quarry.	Sintz quarry.	Holcomb's quarry, lime rock.	Holcomb's quarry, building rock.
Silicious residue	0.65	0.66	1.55	0.59	0.68	1.37	7.37
Alumina and iron	0.56	0.42	0.39	0.39	0.37	0.54	0.96
Carbonate of calcium	54.13	53.51	53.88	53.77	53.92	53.44	50.13
Carbonate of magnesium	44.37	44.96	43.79	44.76	44.99	44.49	40.64
Totals	99.71	99.55	99.61	99.51	99.96	99.84	99.10

The analyses of the preceding tables are all of the Springfield formations, at its best expression.

An analysis of the Clinton limestone, made by Wormley (1869) and another, quoted by N. W. Lord, Vol. 6, p. 682, shows a most radical difference between this stratum and the Niagara, immediately on top of it. Both analyses were made from samples taken at New Carlisle, on the western edge of the county. The figures are:

	Wormley 1869	Lord. —
Silicious matter	0.40	0.83
Alumina and iron	....	0.29
Carbonate of calcium	95.60	96.80
Carbonate of magnesium	3.93	2.07
Totals	99.93	99.99

In order to find out whether the same stratum could be found at other points, at the junction of the Hudson River series and the Niagara, Mr. Peppel visited Enon, about six miles southeast of New Carlisle, and secured two samples, a short distance south of the C. C. C. & St. L. R. R. tracks, between Enon and Snyderville. The Clinton is here without the usual covering of lower Niagara, and the stripping of soil is comparatively light for quite a large area. The analyses show:

Number of sample.	125	126
Description of sample.	From top down 8 ft.	Next 6 ft. below sample 125.
Silica	0.84	1.00
Alumina	1.32	0.60
Oxide of iron	0.42	1.70
Carbonate of calcium	83.40	54.08
Carbonate of magnesium	13.93	42.42
Totals	99.91	99.80

These results are disappointing, but foreshadow the situation demonstrated everywhere by the examination of the Clinton viz., its composition fluctuates and that it cannot be said to have a typical chemical character. Therefore, its value as an asset for special chemical industry like portland cement, or sugar manufacture, etc., would require very thorough local investigation before investment, to determine the exact limits for which a given composition holds good.

CLERMONT COUNTY.

This county, lying wholly in the area of the Hudson River group, has never had any important industries based upon its lime resources. The only reference to it in the older work of the Survey calls attention to the fact that the famous Trenton limestone, so valuable in connection with oil and gas elsewhere, is here raised above the water level, being the only place in the state where it appears. The following analysis by Wormley, 1872, shows the composition at that point.

	Per cents.
Silicious matter	12.00
Alumina and iron	7.00
Carbonate of calcium	79.30
Carbonate of magnesium	0.91
Total	99.21

This material is of a sort which would be interesting to the cement manufacturer, if above correctly represents its average composition, but unfortunately it does not appear accessible for anyi mportant industry owing to its proximity to the average water level of the Ohio river.

The limestones of the Hudson River group, lying above the Trenton, have proved unattractive so far to the scientist or the quarrymen. But a single analysis from this county could be found in the older surveys: from New Richmond, on the Ohio river. Mr. Peppel has supplemented this by two samples, taken from a quarry at the base of the Ohio river bluff, owned and operated by Charles Helmering. The section cut represents the top of the lower group of the formation. The section cut was thirty-five feet in height, the bottom being about sixty feet above low water mark.

Number of sample.	78	79	—
Description.	Peppel, from top down 20 ft.	Peppel, next 15 ft. below sample 78.	Wormley, no record.
Silica	38.80	22.70	10.80
Alumina	14.64	9.00	1.40
Oxide of iron	4.10	2.00	....
Carbonate of Calcium	35.00	60.40	86.60
Carbonate of magnesium	3.07	3.13	1.13
Totals	95.61	97.23	99.93

The marked disparity of these results may be due to differences in location in sampling, but is more probably due to the differences in the method of sampling. The method used by Mr. Peppel gives an accurate cross section of the strata covered, and tells what a quarry in that material would yield when worked. Doubtless many hand samples of clean stone could be taken on which the results reached by Dr. Wormley could be duplicated.

The strata at Bethel, in the eastern county line, were also sampled by Mr. Peppel. The sample was cut on the property of J. C. Lovelace. The stone at this point is highly fossiliferous, the samples being composed of them to large extent. It lies near the top of the formation. Sample 91, comprising eighteen feet of the top of the quarry, gives the following analysis:

	Per cents.
Silica	18.74
Alumina	6.80
Oxide of iron	1.90
Carbonate of calcium	68.50
Carbonate of magnesium	3.06
Total	99.00

This does not seem to be an especially favorable showing of the formation, but its high proportion of silica and alumina, due to inclusion of shaly bands, and its low magnesium is typical of the group.

CLINTON COUNTY.

This county has never been active in the production of lime or building stone, though it is covered on the west by the Hudson River group and on the east by the Niagara. No work on the lime industries appears to have been done by the earlier surveys.

The composition of the Hudson River group on the one hand, and the Niagara on the other, being better known, it was decided to concentrate the attention of the present work on the Clinton, the thin stratum separating these two formations, especially as the older reports claimed it to be a high-calcium lime of great purity, at least in places. Accordingly the point of juncture was examined by Mr. Peppel at three places: Lumberton, in Liberty township on the north; Wilmington, in the center; and Lynchburg in Clark township on the southern edge. Mr. Peppel says as follows concerning these samples: "On Painters Creek, between Lumberton and McKays, and about fifteen miles north of Wilmington, there is considerable acreage of stone belonging to the lower part of the Niagara and comparable to that quarried at Wilmington, and represented by sample 107 at that point. There would be a very light stripping here to uncover five feet six inches to six feet of good stone of the same physical character as the famous Dayton stone. Sample 109 was taken from here, from the lower Niagara. The top of the stone has been planed off smooth, and brought almost to a polish, by erosion of some sort.

"The Clinton limestone was sampled near by, on the farm of Wm. F. Oglesby. At the base of sample 110, there is a curly thin-bedded layer, darker in color than the upper portion, which consists of a crystalline porous stone of reddish color, resembling to a considerable extent the samples taken at Enon. Sample 110 was a section of twelve feet thickness. Sample 111 was the next seven feet below, and was a much heavier bedded and harder stone. Two miles west of Wilmington, George H. Benlehr, and several others, are quarrying about five feet of a fine light-colored building stone, closely resembling the same formation as found near Dayton. Sample 107 was taken from the Benlehr place, and classed as the lower portion of the Niagara. Samples of the underlying Clinton were obtained from the land of John Ballard, about two and one, half miles west of town and one-half mile north of Todds Fork bridge-the point at which the overlying Dayton stone was sampled. The Ballard quarry has long been operated for building stone, the lower courses being even in bedding and furnish a fine bridge stone. This is the only point in the Clinton formation visited which showed a desirable building stone, and one which could be worked with economy. The upper courses are now crushed and used for road metal, as they show an uneven bedding and the shale interstratifications peculiar to the top of this formation. At other points in this neighborhood, a little of the Clinton is quarried for road metal.

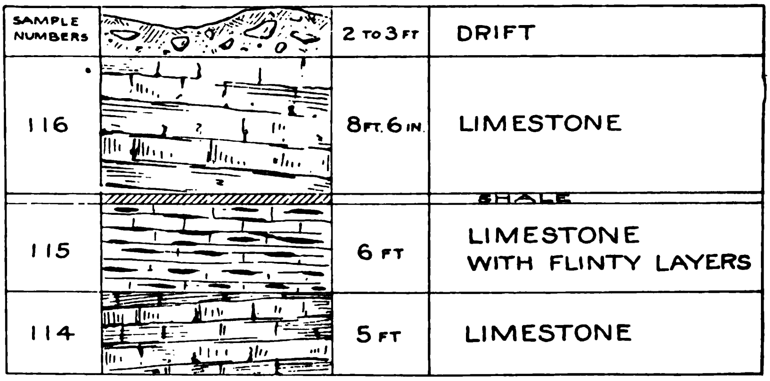

Figure 1.—Showing a cross-section of Clinton limestone, at the Pinkerton quarry, near Lynchburg.

"At the Daniel Sharp quarry, two miles east and one-half mile north of Lynchburg, sample 113 was taken of the same lower element of the Niagara represented in samples 109 and 107. Sample 112 was a soft shale overlying the limestone. This location is about one-half mile north of the R. P. Pinkerton quarry on Turtle creek, where samples Nos. 114, 115 and 116 were taken from the Clinton. (See figure 1.)

"The top layers of the Clinton were at one time burned, giving a hot gray lime. In the section sampled at this point, there occurs a bed of stone about six feet thick, which carries layers of flint nodules, one for each foot in height. A thin deposit of shale forms a cap for this bed. The flint bed is represented by sample 115, and comes in the middle of the section, as may be noted from the drawing. The stripping is not heavy at this point. It is not far from this, however, to points which show the Dayton stone or lower Niagara."

The samples taken in each section include at least one member from the lower Niagara, as this formation would have to be stripped off to get at the Clinton. The analyses are given in the following tables:

Number of sample.	109	110	111	107	104	105	106
Description.	Lower Niagara, Lumberton, 5 ft. 6 in.	Clinton, from Lumberton, top, down 12 ft.	Clinton, from Lumberton, next 7 ft. below 110.	Lower Niagara, from Wilmington, 5ft. 6 in.	Clinton, from Wilmington, top, down 9 ft.	Clinton, from Wilmington, next 9 ft. below sample 104.	Clinton, from Wilmington, next 7 ft. below sample 105.
Silica	1.94	1.80	17.80	3.00	2.10	2.32	10.04
Alumina	1.20	0.85	4.18	0.97	2.21	1.53	3.10
Oxide of iron	trace	0.75	3.30	2.47	3.07	1.15	2.60
Carbonate of calcium	94.42	93.90	45.58	63.09	87.07	83.77	49.70
Carbonate of magnesium	2.19	2.78	29.94	30.20	4.92	10.20	33.48
Totals	99.75	100.08	100.80	99.73	99.37	98.97	98.92

Number of samples.	112	113	114	115	116
Description.	Soft shale, lying on the lower Niagara limestone, 4 ft. 6 in. thick.	Lower Niagara limestone, 4 ft. 6 in. thick.	Clinton, from Lynchburg top, down 8 ft. 6 in.	Clinton, from Lynchburg, next 6 ft. below sample 114.	Clinton, from Lynchburg, next 5 ft. below sample 115.
Silica	33.58	4.88	2.96	19.10	8.70
Alumina	13.68	1.52	0.81	1.04	2.51
Oxide of iron	3.20	3.66	0.75	0.90	1.55
Carbonate of calcium	27.50	64.55	94.48	77.45	74.78
Carbonate of magnesium	17.04	25.51	0.98	1.24	12.09
Totals	95.00	100.12	99.98	99.73	99.63

A consideration of these three sets of analyses discloses the fact that the Clinton shows, in its upper strata, for thicknesses varying from nine to fourteen feet, a low percentage of magnesia, accompanied with high percentages of lime, and a composition favorable for portland cement manufacture. The lower portion is in every case magnesian to a greater degree than is common in the underlying Hudson River formation. It is overlain with beds which Mr. Peppel diagnoses as lower Niagara, and which in two of the sections are strongly magnesian, but in the third case are as pure a high calcium lime as can be found in the Clinton or elsewhere. The physical or lithological character of the three strata which vary so markedly in composition he reports as being very similar. Whether the stratigraphical interpretation be correct or not, it is certainly true that a formation of low-magnesia, high-calcium lime to the aggregate thickness of seventeen feet six inches does exist at the Lumberton quarry.

The economic significance of these facts is that this county contains, in addition to the usual white limes which are so highly prized for mortar material, also a narrow band of pure limestone, at present mainly used for building stone, which would make an undesirable mortar lime, but may become vastly more valuable for use in the chemical industries when pure limes are needed.

COLUMBIANA COUNTY.

This territory lying wholly in the coal measures has no large or important limestone beds. The lowest formation represented above drainage is the top of the Pottsville, whose limestones, the Upper and Lower Mercer, are here thin and of no economic importance. The great part of the county lies in the Allegheny group, which carries the Ferriferous limestone near the bottom, and the lower Freeport limestone at the top. The former is unworkable, but the latter is favorably used for a hydraulic or roman cement, on a small scale. The tops of the hills, especially in the south, are made up of rocks of the Conemaugh formation, in which the upper Freeport or "White" limestone of Newberry is locally rather prominent, though but little use has been made of it.

The Lower Freeport limestone has been analyzed frequently in connection with its use in the cement plant. The industry has been a small one for many years and shows no tendency to growth. Whether the limestone is the limiting factor or not, can only be surmised.

The methods of burning and grinding of the cement produced could certainly be much improved and cheapened, but the stone is present in but a thin vein, and while it can be gotten to supply a small plant, might not be obtainable rapidly enough to supply a large one.

Neglecting the analyses made by Schweitzer and Wormley in 1869 and 1870, the following five by Professor Lord have been compiled, to which are added Mr. Peppel's recent work:

Analyst.	Lord.	Lord.	Lord.	Lord.	Lord.	Peppel.	Peppel.
Description.	Upper Freeport or "White" lime of Newberry. Stock's quarry—1884.	Lower Freeport, or "Cement Rock," Top stratum—1884.	Lower Freeport, or "Cement Rock," Middle stratum—1884.	Lower Freeport, or "Cement Rock," Bottom stratum—1884.	Lower Freeport, or "Cement Rock," Average cross section of vein—1888.	Lower Freeport, limestone at Robbins. Sample 178, 34 in. thick.	Upper Freeport, limestone at Rodgers. Sample 181, 4 ft. 6 in. thick.
Silica	9.01	12.63	33.93	36.69	15.65	17.76	25.44
Alumina	3.38	5.04	14.30	15.17	6.80	7.94	10.62
Oxide of iron	....	2.43	4.29	4.82	2.50	1.86	2.34
Carbonate of calcium	85.55	75.51	35.56	27.22	69.00	66.25	55.59
Carbonate of magnesium	2.82	3.86	6.09	7.83	3.40	2.82	2.14
Totals	100.76	99.49	*94.17	†91.73	97.35	96.63	.96.13

*Combined water and moisture 5.20. Total 99.37.
†Combided water and moisture 7.60. Total 99.33.

Of these, all but the last are from the Robbins cement plant or its vicinity. All these results confirm the fact that the Robbins cement, while manufactured like any other roman cement, is a low magnesia material, differing widely from the Louisville and other cements with which it competes.

West of Wellsville and north of Irondale there appears in the tops of the highest hills a bed of crinoidal limestone, about ten feet thick, which was at one time used as a flux for the blast furnace operated at Irondale many years ago. A sample was secured by Mr. Peppel from a deserted quarry. The sample covers a section of seven feet. There was, however, from two to three feet more that could not be readily reached. The stone is firm, gray, fossiliferous, hard and brittle and would quarry easily. At the point sampled, a few acres could be obtained with light stripping. The analysis follows:

		Per cent
Sample No. 177.	Silica	6.50
	Alumina	1.87
	Oxide of iron	0.71
	Carbonate of calcium	89.70
	Carbonate of magnesia	1.20
	Total	99.98

This stone would be excellent for portland cement, but would not make a good lime for any but agricultural purposes. On account of the high silica, it would have some hydraulic properties when properly burned. The quantity available and its distance from transportation facilities make it seem impossible that it will be developed, unless it is found in larger quantities in the hills to the south and west, in Jefferson county.

CRAWFORD COUNTY.

The western half of Crawford county is overlaid with the Corniferous limestone of Devonian age. The country being flat and drift covered, the stone shows out in but few places.

The Broken Sword Stone Company, at Spore, on the T. & O. C. R. R., are operating a quarry with modern equipment. Mr. Peppel states that the stone is blue or grayish in color and thin bedded. The lower courses are heavier and furnish some handsome building stone. No samples were taken, but the two following analyses were obtained from the firm:

	Spore. Average of 10 analyses 24 ft. of rock face.	Spore. 1 analysis, probably from the lower courses.
Silica	1.87	8.92
Alumina	0.37	3.99
Oxide of iron	....	....
Carbonate of calcium	87.81	56.04
Carbonate of magnesium	9.50	27.82
Totals	99.55	96.77

The strong difference between the single sample and the averages confirms Mr. Peppel's assumption, that the single sample is from the lower stratum only. This corresponds to the differences existing elsewhere between the upper, thin-bedded, Delaware limestone and the heavy, thick-bedded, Columbus limestone which underlies it.

No other working of note occurs in this county at present.

DARKE COUNTY.

This county lies wholly within the Niagara formation. The character of the stone has been made clear in the older Surveys, showing it to be a purely dolomitic stone, as is the case in this formation elsewhere. The lime industry or the quarrying of building stone has apparently never been an important business here, though quarries have been opened for local use in a number of places.

The analyses of the stone of this county compiled from the older reports, together with two new ones by Mr. Peppel, follow:

Analyst	Wormley.	Wormley.	Wormley.	Orton.	Peppel.	Peppel.
Number of samples	—	—	—	—	31	32
Description	New Madison. Northrop's quarry.	Greenville. Gard's quarry.	Greenville. Bierly's quarry.	Greenville.	Gettysburg. Taken from rock already quarried. Not a section.	Gettysburg. Taken from rock already quarried. Not a section.
Silica	2.70	2.20	4.60	0.61	0.88	0.60
Alumina				0.37	0.84	0.70
Oxide of iron	....	....	....	....	....	....
Carbonate of calcium	51.70	51.30	44.60	61.33	54.70	55.50
Carbonate of magnesium	45.72	45.72	50.11	37.68	43.38	43.68
Totals	100.12	99.22	99.31	99.99	99.80	100.48

The two recent samples were from a quarry several miles east of Greenville, near Gettysburg. The only opportunity to get anything was a pile of quarried rock, from which no idea of the section could be obtained. The new analyses confirm the old, entirely, as to character of the rock.

DEFIANCE COUNTY.

This area is covered with the Devonian shales in the upper and larger portion. The Corniferous limestone is the surface rock in the southern edge of the county. There has been very little work done in the quarrying of lime here. There is an interesting roman cement industry near Defiance, founded on the burning of the shales which lie on the top of the Corniferous limestone. These shales are locally carboniferous, which assists in their burning, and also calciferous, to an unusual degree. They also contain pyrites in bands, which is troublesome, as it is detrimental to the cement to have this sulphur go into the mixture.

The Corniferous limestone was sampled by Mr. Peppel at a point four miles southwest of Defiance, in the bed of the Maumee river, not far from the low water channel. The quarry belongs to Snyder Brothers. They dike the water out of the quarry, at ordinary stages, without much difficulty, especially in the summer. The limestone is blue-gray in color with numerous flint layers. The bedding is not altogether even. The stone is probably the Delaware phase of the Corniferous, though lighter in color than this stratum appears elsewhere. This sample was taken at a point a little further up stream, than the cement-shale quarry above described. The analyses of the two materials follow:

Number of samples	—	26
Description	Shale, burned for hydraulic cement, at Defiance. (Bleininger Bul. 3).	17 ft. section top of Corniferous, near Defiance. (Peppel).
Silica	23.34	11.86
Alumina	8.70	1.58
Oxide of iron	1.60	traces
Carbonate of calcium	38.34	55.30
Carbonate of magnesium	23.24	32.21
Totals	95.22*	100.95

*Carbonaceous matter makes up bulk of balance.

The composition of the Corniferous is unusually magnesian at this point.

DELAWARE COUNTY.

The western third of Delaware county is covered by the Corniferous formation, with a little of the Waterlime appearing on the northwestern corner. The quarries at Delaware are old and well known. They are in the upper portions of the Corniferous which is now recognized as a distinct stratigraphical element in the series, under the name of *Delaware limestone.* This formation is here a hard, blue, somewhat flinty stone. Mr. Peppel says, "The samples were taken in the F. S. Campbell quarry, near the depot of the Hocking Valley railroad. Sample No. 5 was the gray, shelly caprock, carrying flint nodules. No. 6 was the famous blue stone of Delaware, known for its uniform good color, and even bedding. Some layers of this stone carry flint nodules and must be discarded for building purposes. The bottom of sample 6 is probably within a few feet of the bottom of the Delaware formation. There is a fault in this quarry, by which the strata are displaced about one foot from the level seen elsewhere in the same quarry.

"The Columbus limestone, or the lower member of the Corniferous formation, is worked at Scioto, a few miles west of Delaware. The location is given under the name of White Sulphur, as that is the nearest railroad station.

"The stone is used for lime, and is almost identical in position with the lowest sample analyzed from the Marble Cliff quarries west of Columbus.

"An analysis of their stone was furnished by the proprietors."

Number of sample.	5	6	—
Description.	Delaware—Top 5 ft. 6 in. grey, shelly stone.	Delaware—Next 24 ft. below sample 5, blue, well bedded stone.	Columbus limestone, from White Sulphur. Used for lime. Analyst not known.
Silica	3.02	10.36	1.30
Alumina	0.95	2.71	0.28
Oxide of iron	0.25	0.05	....
Carbonate of calcium	91.31	69.80	92.64
Carbonate of magnesium	5.12	17.21	4.75
Totals	100.65	100.13	98.97

The upper portion of the Delaware bed is thus seen to be rather low in magnesia, and of possible use in cement manufacture, while the lower becomes magnesian and worthless for this purpose. Its fine qualities as a building stone and its poor qualities as lime make its use in the latter capacity doubtful. The White Sulphur analysis is a very pure and high-calcium phase of the Columbus limestone. It is doubtful if these figures could be duplicated on a representative sample, taken by the usual methods of the survey. Nevertheless, the divergence from the figures of the equivalent stratum at Columbus are not very great.

ERIE COUNTY.

About one-third of this county, the northwestern corner, is covered with the Corniferous limestone as the surface rock. Extensive quarries have been located around Sandusky for many years, as well as on the peninsula across Sandusky bay and on Kelley's island. In fact, this district is one of the great stone and lime-producing centers of Ohio. It has been carefully studied and reported upon in Vol. V., p. 534, Vol. VI., p. 753-5, Vol. VII., p. 707. The analyses given at those points are here collated. No new work was done in this district.

Dr. Orton, V. 6, p. 753, comments on the rejection of limestones showing from 97 to 87 per cent. of calcium carbonate and the selection of limestones ranging from 77 to 71 per cent. of calcium carbonate with 20 to 27 per cent. of magnesium carbonate for lime burning purposes.

He says that the analyses of blue cap rock from Kelley's Island, showing such remarkable purity, was made from only one piece of the stone, and thinks the stratum would not afford such material as an average.

Analyst.	C.R.M. Co.	Lord	Lord	Lord	Lord	Lord
Name of quarry.	Kelley Isd.	Calkins	Kelley	Kelley	Kelley	Kelley
Date of analysis.	1884	1886	1888	1888	1888	1888
Description of sample.	Flux stone, used for iron smelting.	Burnt for lime for Cleveland market.	Blue cap rock. Rejected.	Ordinary cap rock, used for flux stone.	Bedded stone, used for building purposes.	Burnt for lime.
Silica	1.81	1.60	0.85	1.49	1.05	1.65
Alumina and iron	0.75	0.40	0.27	0.15	0.20	0.14
Carbonate of calcium	87.50	71.17	97.28	87.10	89.16	77.22
Carbonate of magnesium	9.75	26.82	2.00	10.96	9.48	20.19
Totals	99.81	99.99	100.40	99.70	99.89	99.20

In addition to the limestone, there are or have been somewhat extensive beds of marl, and a hard lime deposit of recent origin, called travertine. These have given rise to extensive portland cement industries, and all the land on which the deposits are found have been anxiously acquired. In fact, one firm, after a number of years of very successful operation, is now approaching the end of its available supply. These marl beds are thought to be lake bed deposits and never of great area, so that while they are of great value when discovered, if of proper thickness and accessibility, still they are not to be construed as an asset of importance equal to the great rock formations whose permanence is assured.

The composition of the marl and travertine are sufficiently indicated by the following analyses quoted from Klippart, Rep. Pro., 1870, p. 379.

Description of samples.	Travertine, from Castalia.	Marl, from Castalia.	Marl, from Castalia.
Silica	0.175	0.075	0.111
Alumina and oxide of iron	0.862	0.362	0.012
Carbonate of calcium	87.775	97.726	92.410
Carbonate of magnesium	2.209	1.480	2.853
Sulphate of baryta	0.910	0.356	......
Water and loss	8.069	......	4.525
Totals	100.000	100.000	99.91

There is no purer source of lime anywhere obtainable in the large way than many good marls. Nevertheless, there is a considerable difference of opinion as to the relative advantages which hard limestone and soft marls offer for portland cement manufacture. At one time, the opinion seemed strongly in favor of marls as the most desirable, but this belief seems to have recently lost ground. In any case, the use of the solid, hard limestones will ultimately become nearly universal, as the scattered marl beds are worked up. They do not seem to promise to become assets of great permanent value to the community.

FAYETTE COUNTY.

Though covered exclusively by limestone as the nearest superficial rock, this county is singularly devoid of industrial development of its lime or quarry industry. The only references found were analyses from two quarries, probably long since abandoned, but which suffice to show the characteristic stone of the Waterline formation, in which they are located.

The results are given below. The analyses were by Wormley.

Description of samples.	Doster's quarry, Green township.	Rittenhouse quarry, Wayne township. No. 1.	Rittenhouse quarry, Wayne township. No. 2.	Rittenhouse quarry, Wayne township. No. 3.
Silica	6.00	4.80	3.60	2.80
Alumina and iron	2.30	2.60	2.20	2.90
Carbonate of calcium	52.40	53.60	54.00	53.60
Carbonate of magnesium	38.73	38.30	39.50	40.28
Totals	99.43	99.30	99.30	99.38

The text states that the Rittenhouse lime had an approved use in its locality as a hydraulic lime, but this seems hardly borne out by the analyses which are too low in silica and alumina to foreshadow much hydraulicity.

FRANKLIN COUNTY.

Substantially one-third of the county, its entire western end, is covered with the Corniferous limestone in two formations, the Delaware, a thin, shelly, often flinty limestone, of little value for anything but crushing, as it appears in this territory, but furnishing excellent hard building stone to the north; and the Columbus limestone, a massive bed forty to fifty feet thick, and of great value for lime, for building, for flux, for crushing, in fact, nearly all purposes to which a limestone may be applied.

These stones are quarried upon an enormous scale about four miles west of Columbus, on the Scioto river. The industry is an old one, the stone having been worked for many years prior to the building of the

Capitol, in 1855–60, which event gave a great impetus to the quarries. In recent years the old business in building stone has largely dropped away, but has been replaced by a much larger one in the production of crushed rock for ballast, for concrete, etc.

The studies of the early geologists have left the nature of this stone well known. The results reached by the previous Surveys are collated herewith:

Analyses of Columbus Limestone.

Analysts.	Lord.	Lord.	Lord.	Lord.	Mees.	Mees.	Mees.
Description of sample.	Average of 8 separate analyses, Columbus quarries.	Stratum known as "smooth rock."	8 ft. from "smooth rock" up. Lillie's quarry.	6 ft. from "smooth rock" down. Lillie's quarry.	6 ft. from "smooth rock" down. Smith & Price quarry.	Building stone courses below last sample. Smith & Price quarry.	Selected sample of best rock. Smith & Price quarry.
Silica	4.25	5.80	4.90	4.95	1.41	1.94	3.20
Alumina Oxide of iron	0.26	1.30	0.09	0.46	2.18	1.08	0.80
Carbonate of calcium	94.19	87.25	89.60	90.77	93.28	81.14	94.80
Carbonate of magnesium	1.29	5.26	4.41	3.26	2.69	16.00	1.21
Totals	99.99	99.61	99.00	99.44	99.56	100.16	100.01

The work of the present organization was confined to one set of three samples from the Columbus quarries, and one sample from Morgan's station, in the southern end of the county, both taken by Mr. Peppel. His remarks follow:

"The various Columbus quarries are located on either side of the Scioto river, extending for several miles above the State Hospital for the Insane. The stripping is usually light and the quarries self-draining. Occasional vertical mud seams are met, some of which are as much as three feet in thickness. The economic conditions here are excellent for cheap production.

"Samples were taken from the Taylor-Bell Company's quarry, on the west side of the Scioto at Marble Cliff.

"The Delaware formation here shows only as a very impure slaty material. It is comprised in sample 101, taken from six feet six inches of vertical section. No. 2 was the next eight feet below, which includes a layer high in phosphorus, and which is rejected for fluxing purposes on that account. This stratum is used only for building stone or for crushing purposes at this point. Sample No. 3 represents the whole remaining section of the quarry, about thirty-eight feet, which is composed of massive courses, evenly bedded, and satisfactory either for a flux rock or heavy construction. The phosphorus ranges from 0.008 to 0.002 per cent. This locality furnishes more flux to blast furnaces than any other locality in the state.

"Sample No. 4 came from land owned by the State Institution for the Feeble-minded, at Morgan's Station. The quarry from which it was taken was a shallow one, and was not being worked at the time. The total height sectioned was about thirteen feet. The stratum known to palæontologists as the Eridophyllum bed was the top of the section."

The analyses follow:

Number of samples.	1	2	3	4
Description.	Taylor-Bell quarry. 6 ft. 6 in. cap rock. Delaware. Formation, flinty.	Taylor-Bell quarry. Next 8 ft. below sample 1, including "Bone Bed."	Taylor-Bell quarry. Next. 38 ft. below sample 2. Massive heavy courses. Columbus formation.	Morgan station. 13 ft. from surface.
Silica	30.06	10.30	2.30	1.54
Alumina	3.08	1.15	0.70	0.48
Oxide of iron	0.10	0.05	trace	trace
Carbonate of calcium	54.60	81.60	91.66	88.85
Carbonate of magnesium	10.45	7.62	6.06	9.82
Totals	98.29	100.72	100.72	100.69

Mr. Peppel's samples, representing faithfully the composition of a cross section of these great quarries, are valuable especially in conjunction with the testing of the former work. It tends to show:

First: That the Delaware formation, which is low in magnesia in its upper layers, but magnesian in its lower portion, is represented in Columbus by the lower portion or that the whole stratum has undergone a change in composition. The former is the more probable.

Second: That the Columbus formation, the heavy bedded courses below the Delaware, is characteristically rather low in magnesia. The average figures include undoubtedly some strata higher in magnesia than others. But, with the average as low as six or seven per cent., and with numerous individual samples showing from 1.25 to 5.25, it seem highly probable that considerable bodies of low magnesia stone of portland cement grade may be obtained. As to its fitness for white lime, its heat on slaking makes it unpopular with builders, but as mechanical slaking and mechanical mortar-making gradually supersede the primitive method, the excellent mortar-making qualities of this lime are going to be more and more recognized.

Third: It seems sure that for any chemical industry requiring high-calcium lime, that great care and constant attention would be required to keep the composition uniformly good. The magnesia is often low, but its average is put above the danger limit. Its satisfactory use for so many other things makes it seem doubtful if it will be selected for the basis of an important cement industry.

GALLIA COUNTY.

The western edge of Gallia county, especially in Greenfield township, contains the Ferriferous limestone in good development. It has been quarried at Gallia Furnace on a small scale, about seven thousand tons having been taken out by Isaac Hall. The stone here is about six feet seven inches, not quite up to the phases shown either north or south of this point. A sample was taken, but was lost in transit. Without doubt the stone is similar to the Eifort or Olive furnace products, as it is free from flint and looks as good as this formation does anywhere. The areas in this vicinity where it could be gotten are fairly large.

To the east and southeast, the Ferriferous soon goes under cover; the upper limestones of the Freeport, Cambridge and Ames horizons come in, but so far as is known not in workable thickness.

GREENE COUNTY.

Greene county has been the site of important lime industries for many years. The territory is almost evenly divided between the Hudson River series on the west and the Niagara on the east, with the Clinton showing between the two in many sections.

The lime industry has attracted the attention of the early geologists, so that the character of the stones which have received commercial development is very well known. These comprise the Niagara limestone almost exclusively, which manifests here the most beautiful uniformity and purity as a type of dolomitic limestone. Where impurities occur in the form of flint, or clay, they simply cut down the quantities without altering the proportions of the lime and magnesia to each other. The following analyses with one new one by Mr. Peppel sufficiently illustrate these facts.

Analysis of the Niagara Limestone.

Analyst.	Wormley.		Lord.		Lord.		Wormley.	Peppel.
Date.	1869.		1888.		1888.		1869.	1902
Locality.	Yellow Springs.		Yellow Springs.		Cedarville.		Cedarville.	Port Will'ms
Description of sample.	Sroufe's quarries. Best stone.	Sroufe's quarries. Blue building rock.	Irvin's quarry, average of rock used for lime.	Irvin's quarry, average of rock used for building.	Ervin's quarry. No. 1.	Ervin's quarry. No. 2.	Best Cincinnati stone.	7 ft. stratum, used for lime. Sample 108.
Silica	0.40	5.40	0.72	5.65	0.58	0.88	0.72	0.60
Alumina and oxide of iron	2.00	1.40	0.51	0.76	0.57	0.53	1.00	0.76
Carbonate of calcium	54.75	51.10	53.98	50.75	53.95	53.90	54.90	54.50
Carbonate of magnesium	42.23	41.12	44.56	41.86	44.62	44.58	43.35	43.33
Totals	99.38	99.02	99.77	99.02	99.72	99.89	99.97	99.69

The new sample, from Port William on the southern edge of the county, came from a shallow quarry in the village limits, which is used for lime exclusively. Its composition proclaims its stratigraphical horizon.

Besides the Niagara, there have been occasional openings made into the Clinton, or at least lower beds of the Niagara than those used at Yellow Springs and Cedarville.

The following analyses are reported from these openings:

Analysis of Clinton or Lower Niagara Limestones.

Analyst.	Lord.	Lord.	Wormley.
Date.	1888	1888	1870
Locality.	Osborn.	Osborn.	Xenia.
Description.	Haddock'squarry. Best rock.	Haddock's quarry. Rejected rock.	McDonald's quarry. Dayton stone.
Silica	1.64	0.70	2.20
Alumina and oxide of iron	0.36	0.41	2.00
Carbonate of calcium	97.09	97.14	84.50
Carbonate of magnesium	0.82	1.21	11.16
Totals	99.91	99.46	99.86

The Xenia sample is thought to be the "Dayton" stone, the white, crystalline, very dense stone so largely used as a building material in Dayton. Its analysis seems to show that it is not the Cedarville or Yellow Springs stratum. The Osborn samples are referred to as the Clinton, in the early volumes, and attention is called to the Clinton formation as the source of such pure high calcium stone—the New Carlisle and Osborn samples were used to illustrate this fact.

The attention of the present Survey in this county was largely directed to finding whether the Clinton really may be depended on to furnish stone of this character in other than occasional patches of small area. Mr. Peppel's work was along the edge of the Niagara and Hudson River formations, or in sections where both could be seen,rather than in the well developed and well understood quarries of the Niagara.

Two careful sections were made, one at Yellow Springs on the north, the other at New Jasper on the east center. The Lumberton sample in Clinton county was almost on the south line of Greene county and hence establishes our knowledge of the formation in a row of points.

Mr. Peppel says of these samples: "The Yellow Springs samples were taken on the Sheldon place, about one mile south of town, in which the commercially known quarries (Niagara) are located. Sample 127 lay near the top of the Clinton, and consisted of layers of uneven red and white crystalline stone, with numerous thin shale bands. No. 128 consisted of heavier beds, still uneven in bedding and having some layers which were hard and some which were soft. No. 129 was in still heavier beds but porous and soft. This sample reached very near if not actually to the bottom of the formation.

"The New Jasper samples were taken from a quarry being actively operated by Boots, Bales & Conklin. There is a rather heavy stripping here to uncover the stone. The quarry cuts through the lower Niagara into the Clinton, exposing both formations very nicely. The following section represents the strata; it may be said to be an average cross-section of the Clinton as seen in this investigation.

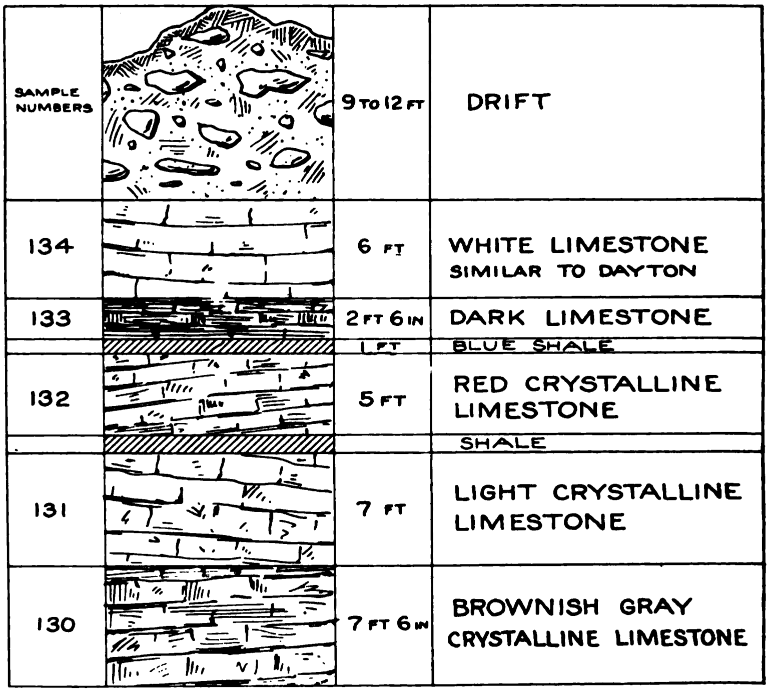
SAMPLE NUMBERS
9 TO 12 FT
DRIFT
134
6 FT
WHITE LIMESTONE SIMILAR TO DAYTON
133
2 FT 6 IN
DARK LIMESTONE
1 FT
BLUE SHALE
132
5 FT
RED CRYSTALLINE LIMESTONE
SHALE
131
7 FT
LIGHT CRYSTALLINE LIMESTONE
130
7 FT 6 IN
BROWNISH GRAY CRYSTALLINE LIMESTONE

Figure 2.—Showing a cross-section of the Lower Niagara and Clinton limestones as seen at New Jasper.

"The only use to which the Clinton rock is put here is for crushed stone or ballast. The Niagara stratum, or Dayton stone as it is thought to be, is a white, even-bedded stone of excellent quality for building purposes."

The analyses of these two sets of samples follow:

Locality.	Yellow Springs.			New Jasper.				
Number of Sample.	127	128	129	134	133	132	131	130
Description.	Top, down 8 feet. Clinton formation.	Next 8 feet below sample 127. Clinton.	Next 9 feet below sample 128. Near bottom of Clinton.	Top, down 6 feet. Dayton limestone of Low Niagara.	Next 7 feet 6 inches below sample 134. Darklimestone.	Top of Clinton down 5 feet. Red crystalline stone.	Next 7 feet below sample 132. Light colored stone.	Next 7 feet 6 inches below sample 131. Brownish grey stone.
Silica	4.28	1.53	0.72	5.70	9.16	10.32	9.30	2.54
Alumina	1.37	1.30	0.45	2.20	2.69	5.73	4.38	0.69
Oxide of iron	1.51	0.90	1.95	1.20	3.25	4.07	0.60	1.71
Carbonate of calcium	67.21	77.35	68.20	72.20	54.43	71.78	81.92	75.27
Carbonate of magnesium	25.04	19.45	28.44	18.25	30.42	7.36	3.24	20.60
Totals	99.41	100.53	99.76	99.55	99.95	99.26	99.44	100.81

A study of these results is somewhat disappointing. In neither locality is the promise of the Osborn sample made good. Admitting that Mr. Peppel's identification of the strata is correct, and there is no reason to doubt it, the Clinton is again shown to adhere closely to no type of composition. The Yellow Springs samples all are highly magnesian, and worthless for cement or other chemical uses. The New Jasper samples on the other hand show a marked falling off in magnesia, but unfortunately not a proportionate rise in calcium, as the silica and alumina and iron are all high.

No. 131 might be used in cement, but as a formation the results are prohibitive, and the use of one stratum alone for a special purpose is not warranted, except where the product commands a high price. Cement works require enormous quantities, handled cheaply and sorting operations are commercially out of the question, though technically possible.

GUERNSEY COUNTY.

Guernsey county lies wholly in the coal measures, its surface formations comprising the upper portion of the Allegheny and the Conemaugh on the west, and the Conemaugh and Monongahela in the center and east. The limestones of the Allegheny are unimportant, being thin and unworkable for an industry of large size. The Cambridge limestone, in the Conemaugh, is locally well developed, taking its name from the county seat. It is valuable more as a stratigraphical guide, however, than as a source of lime. But one analysis can be given from this vicinity, and it is not surely known as Cambridge, but probability points to this origin. The analysis is by Wormley, in 1870, but no details or reference to it elsewhere in the report can be found:

Analysis of Scott's Limestone, Cambridge.

	Per cents.
Silicious matter	30.60
Alumina and iron	3.60
Carbonate of lime	64.60
Carbonate of magnesia	1.20

The thickness of the Cambridge limestone is reported to be from five to even twelve feet in this vicinity, but no workings now open could be found to sample. The low magnesia in the Scott analysis is significant. It is highly probable that other exposures can be found in which silica and lime would reciprocally vary, but the stone is usually low in magnesia and therefore has possibilities for portland cement work.

In the eastern and southern part of the county, the Pittsburg and Meigs Creek coals are uniformly present, with the limestone above and below them, which are noted in much more important degree to the southeast. But one sample was taken, at Cumberland, in the southwestern corner of the county, on the border of the Pittsburg and Meigs Creek limestone areas. The sample was obtained from the following section, of which a part only is here given:

		Feet.	Inches.
	Buff limestones	40–45	0
	Purple and green shales	..	..
	Meigs Creek coal (No. 9)	4	0
Sample 153	Fireclay,	2	0
	Limestone	7	0
	Shale with kidney ore at base	20	0
	Sandstone	18–20	0
	Coal	2	4

Some time was spent in search of an opportune location to sample the upper group of limestones, but none was found, and in view of the number of similar samples taken it was not deemed wise to go to the expense of making excavations where strata were only partially exposed. Of the sample taken, No. 153, Mr. Peppel says, "No. 153 came from J. M. Hunter's farm, three-fourths of a mile south of Cumberland. The stone had been quarried at this point for local use. The workings were on a small scale. The thickness of the vein sectioned in the sample was seven feet."

		Per cents.
Sample 153.	Silica	7.24
	Alumina	1.48
	Oxide of iron	1.20
	Carbonate of calcium	87.47
	Carbonate of magnesium	2.40
	Totals	99.79

This is a good cement rock, though the thickness is at a minimum. The quarrying of the stone would be greatly facilitated, however, by the winning of the coal, which would leave the stone available for blasting and loading with only two feet of fireclay to handle. It is highly probable that search in this locality will open up other well situated areas of this material.

HAMILTON COUNTY.

This area is wholly covered by the Hudson River group of rocks, which are the only strata visible in the county in valleys or hill tops. It seems to have been concluded by the geologists of the early Surveys, that no good lime could be made from these beds, as very little work was done in pointing out the composition of the limestones which are the predominant feature of every section. Their thickness and constant intercalation with thin shale bands seemed to the lime burner an insuperable obstacle. The lime produced in a few trials was gray and hence the beautiful white limes of Cedarville, Springfield, and other Niagara localities superseded the dark lime produced locally for most purposes. The dark high-calcium lime produced was used for the building of cellar walls, and six or eight pot kilns have been kept in operation for a great many years, and are still at work, supplying lime mainly for this trade.

The use of limes for other purposes, however, changes the point of view somewhat, and the intercalations of shale strata is not so serious a matter as it was once thought to be, if the stone itself is favorable in composition. That it might prove so, these two old analyses gave ground for thinking. No later figures could be obtained.

Analysis of Cincinnati Limestone.

Analyst.	Locke.	Wormley.
Date.	1838.	1872
Silica or silicious matter	2.57	23.48
Alumina or iron and alumina	3.15	3.40
Carbonate of calcium	90.93	71.30
Carbonate of magnesium	1.11	1.89
Water	1.13	....
Totals	98.89	100.07

The Wormley analysis was from the "River Quarries," probably, therefore, the lower member of the Hudson River series. Nothing is known of the Locke sample.

Two points were selected to represent the strata of this county, viz: Glendale on the northern edge, and Cincinnati on the south. Mr. Peppel's observations and results follow:

"The Glendale stone was sampled three miles west of town, on a farm owned by Charles Fields. It occurred in a bare bluff, almost vertical, and about 110 feet high. A few small globular masses of vivianite, or phosphate of iron, were found in the sand and loam deposited by a small stream a short distance below the point sampled."

Analyses of Glendale Limestones.

Number of samples.	71	70	69	68	67
Description.	From top layer down 25 ft.	Next 40 ft. below sample 71.	Omitting 3 ft. next 20 ft. below sample 70.	Next 11 ft. below sample 69.	Next 13 ft. below sample 68.
Silica	24.26	29.80	38.30	31.30	52.38
Alumina	7.99	10.05	13.35	11.47	18.64
Oxide of iron	2.65	2.55	3.65	3.25	4.60
Carbonate of calcium	60.40	50.95	35.90	45.00	13.20
Carbonate of magnesium	2.80	4.40	4.84	6.10	5.36
Totals	98.10	97.75	96.04	97.12	94.18

The Glendale sample holds out no promise of economic value in the lime or cement industry, as the proportions of clay are too high in the purest of the five samples taken. No. 67 becomes merely a somewhat calcareous shale. The magnesia also seems higher throughout than in most other places in this formation.

"Eight samples were taken from the Davis quarry at Cincinnati and adjacent properties which are located near the Avondale power house, on Hunt street." The analyses were as follows:

Analyses of Cincinnati Limestones.

Number of sample.	76	72	73	74	75	77	92	93
Description.	From top layer down 8 ft.	Next 18 ft. below sample No. 76.	Next 17 ft. below sample No. 72.	Next 17 ft. below sample No. 73.	Next 13 ft. below sample No. 74.	From 85 to 107 ft. below top of quarry.	Next 22 ft. below sample No. 77.	Next 19 ft. below sample No. 92.
Silica	33.60	20.66	30.28	33.08	30.00	36.84	38.00	25.04
Alumina	12.00	7.74	10.30	10.78	9.80	11.14	13.80	9.38
Oxide of iron	3.70	2.10	2.40	2.80	2.30	3.30	2.80	2.80
Carbonate of calcium	43.35	63.70	49.60	46.60	51.45	40.90	38.72	58.08
Carbonate of magnesium	2.65	3.58	4.46	4.19	3.75	4.15	3.80	3.02
Totals	95.30	97.78	97.04	97.45	97.30	96.33	97.12	98.32

None of the above evince any important fitness for the lime and cement industry. The material as a whole would make an excellent basis for the portland cement industry, if it were worked in connection *with a pure stone* which could bring up the lime to about 74–75 per cent., with proportionate losses in the other ingredients. Doubtless considerable shaly matter could be rejected from the above stone in working it, if it were desirable to do so. But the intent in this work was to determine what the whole section would give, if taken in such ways as would enable economical handling. Sorting on a large scale is out of the question.

These results do not confirm the promise of the Locke analysis, nor do they encourage the idea of utilizing the Hudson River limestones of this vicinity for such purposes as are now in prospect. This lack of confirmation is probably due to the fact that the earlier workers did not include in their samples shale which is always intercalated with this stone.

HANCOCK COUNTY.

The Niagara occupies the eastern half of the county and the Waterlime the western half. These stones are both capable of opening up and working in many points, but the flatness of the country, the uniform and often heavy coating of drift, and consequently heavy stripping and lack of heavy local demands for lime or stone, make the production of the quarries small. The industry has been carried on at Findlay for a long time, using the lower portion of the lower Helderberg formation. The quarries in 1888 were but about eight feet in depth. Dr. Orton gave an account of its irregularity in his 1888 report. Mr. Peppel reports as follows:

"The Findlay samples came from a quarry operated by Tarbox & McCall, on Factory avenue, who are burning lime and producing crushed stone. The stone was a thin-bedded and somewhat irregular one, of a blue-brown color. It showed the concretions mentioned by Dr. Orton in his early reports as being found in the Waterlime formation. The local terms for these are 'Turtlebacks' or 'Niggerheads.' There are numerous shale-like layers in the quarry. The stone does not stand the weather very well. The stripping is very light. The total depth now quarried is about twenty-one feet."

The analyses of the two reports are given together:

Analyst.	Lord.	Lord.	Peppel.	Peppel.
Number of sample.	——	——	21	20
Description.	Accepted for good lime.	Rejected, makes bad lime.	Top, down 9 ft. 6 in.	Next 12 ft. below sample 21.
Silica	1.55	8.00	0.92	1.36
Alumina Oxide of iron	0.39	1.16	0.52	0.96
Carbonate of calcium	53.88	49.62	55.50	54.90
Carbonate of magnesium	43.79	40.94	43.40	43.42
Totals	99.61	99.72	100.34	100.64

It is evident in this case, that the method of sampling used by Dr. Orton did not in this highly regular and uniform material produce any different results from the cross sectioning method used by Mr. Peppel. This could not be the case in strata of mixed or varied character, however.

The lime is thus seen to be a typical dolomite, of high class, as to composition, though its physical features were pronounced unfavorable by both observers.

HARDIN COUNTY.

This county is practically covered by the Waterlime formation, though the Niagara invades the southwestern and northeastern corners for small areas. There has never been any large lime industry in this county, though its resources are undoubted. In 1888, it was not listed as a lime producing county at all. In 1903, it had taken place in the list as a limestone producer, though not on a large scale. Mr. Peppel says:

"The Kenton samples were taken from a quarry operated by Locey & Company, two miles southwest of Kenton and one-eighth of a mile from the Big Four railroad tracks. This firm is operating for crushed and building stone. The stripping was about two to three feet. The stone was all thin-bedded and dense, carrying some impurities. The bedding was also uneven. Sample No. 40, representing the top five feet, was buff in color; 41, representing the next ten feet below, was blue."

Number of sample.	40	41
Description.	Top 5 ft. down. Buff.	Next 10 ft. below sample No. 40. Blue.
Silica	3.06	1.80
Alumina	2.10	1.04
Oxide of iron	trace	trace
Carbonate of calcium	52.55	53.50
Carbonate of magnesium	42.12	43.10
Totals	99.83	99.44

This stone is a typical showing of the Waterlime, and proves that the county could enter the list of lime producers with a rather dark dolomite lime if it desired.

HIGHLAND COUNTY.

The geology of this county is comparatively complex. Its strata runs from the Hudson River group on the west, to the Devonian shales and sandstones on the east. In spite of the number of elements represented, the surface rocks are largely limestone, and the county is one of the largest producers of quarried stone and lime in the state.

So far as can be ascertained, no use has been made of the limes or limy shales of the Hudson River group on the west side of the county. The nearby presence of a much superior material has prevented any trial of it.

The Niagara formation covers the main part of the county with its several clearly marked divisions. On it, the Waterlime or lower Helderberg lies, in a few islands in the northeast at Greenfield.

The limestones of the upper Niagara and lower Helderberg formations cannot be distinguished from each other by chemical analysis. They are both very pure dolomites, here as elsewhere. Their determination rests, therefore, on physical differences which are very clearly marked.

The Clinton formation, separating the dolomites of the upper division from the shaly limestones of the Hudson River formation, is present in this county in good quantity. It is not and has not been worked on any important scale for either lime or stone. No quarries or openings could be found from which to procure a representative analysis of it.

The work of the previous Surveys has shown the composition of the Niagara and Helderberg when quarried, as in the following analyses, all by Dr. Wormley.

Locality.	Lexington.	Leesburg.	Greenfield.		Hillsboro.			Sinking Springs.
Description of sample.	Pope's quarries. Niagara.	Wright's quarries. Niagara.	Wright's quarries. Lower Helderburg.	Rucker's quarries. Lower Helderburg.	"Lower Cliff" or West Union stone.	Trimble's quarry. Guelph beds.	Trimble's quarry. Blue Cliff or Cedarville stone.	Waterlime or lower Helderberg.
Silica	3.57	1.60	4.35	2.44	2.60	13.30	0.40	0.70
Alumina	0.90	2.20	1.00	1.30	3.20	2.00	1.80	1.50
Carbonate of calcium	49.76	54.10	49.70	53.67	62.60	35.57	54.25	52.87
Carbonate of magnesium	45.77	41.77	44.87	42.42	31.32	49.00	43.23	42.94
Totals	100.00	99.67	99.92	99.83	99.72	99.87	99.68	*98.01

*Phosphate of lime, 1.39 per cent. Total 99.40.

The above localities, save the last, were the site of important lime industries thirty-five years ago. Mr. Peppel in his trip over the county finds the condition still the same. The industries have grown, and are now very large, but no new localities have been opened, and no new developments made, so far as the chemical character of the material is concerned. The following notes refer to the samples taken by him:

Samples taken at Leesburg came from along Lee's creek east of the town. In the vicinity of the place where samples 119, 120, and 121 were taken, there would be a considerable area on which the stripping would be light. The stone is hard and rather even in bedding, especially so

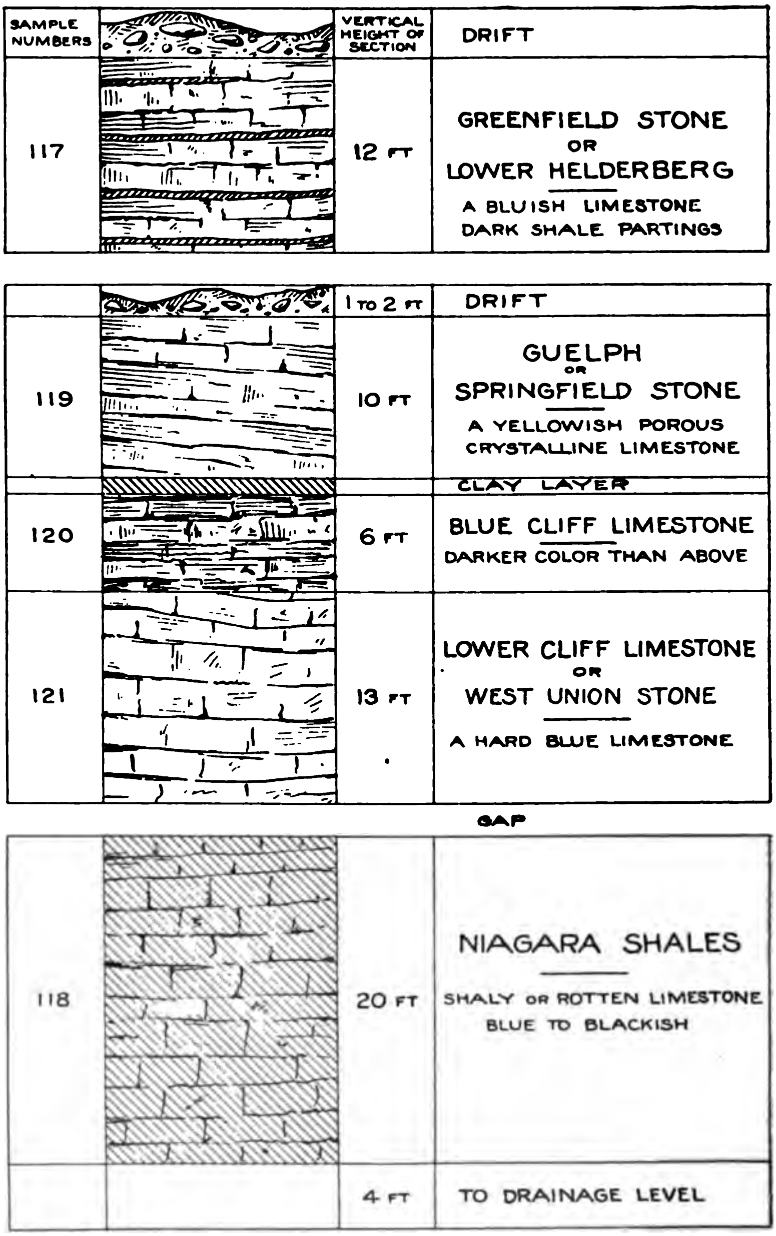

Figure 3.—Showing a cross-section of the limestones opened near Leesburg.

in sample 121, which is in heavy strata, blue in color. This sample reaches pretty well down to the bottom of the formation, but not quite to the underlying shale.

There is a small anticline a little further down the stream, where the underlying shale appears, carrying the limestone upon it; the stratum is the same as shown in sample 121. This shale to the thickness of twenty feet was sampled as number 118. A thin bed of shale also intervenes between samples 119 and 120 and was excluded from these samples.

Sample 117 was taken from the quarry of John F. Lufts. This stone does not agree very well with the neighboring samples in lithological character. It consists of a rather hard, blue, uneven and rather thin bedded limestone, interstratified to some extent with shale from two to six inches in thickness. This sample resembles in physical character the top one at Newport. It seems to be stratigraphically higher than the top of the other group, and is so shown in the section shown herewith, though no attempt is made to exactly correlate it.

Greenfield has long been known for its building stone and locally for its lime. The formation is the lower Helderberg or Waterlime. The samples were taken from the Rucker Stone Company's quarry. The stripping is heavy here, from six to fifteen feet, which is removed by the hydraulic method. This is the only company in Ohio to use this method, up to this date. The building stone contains so much water that it must be dried out before frost; the quarry is not worked in the winter time on that account. This period of rest is used to do the stripping for the ensuing year, and to clean up the quarry.

Sample 122 is a buff stone lying in heavy beds. This is chiefly used for crushed stone or for burning lime. The depth of the cut represented in this sample is thirty-one feet. Sample 123, twelve feet in thickness, is a buff stone in even beds of from three to twelve inches. Sample 124 is also even bedded, but the strata are a little heavier, and the color is darker. The strata representing both of these lower samples are liberally streaked with bitumen, and occasional flint nodules are found. All of this stone is earthy in appearance, lacking the crystalline sparkle of the Niagara. It is all tight bedded, adhering closely, and without fissures, so that blasting is required even for the building stone, to open up working faces. The spalls and broken stuff from the entire quarry are burnt for lime.

At Hillsboro, the Rucker Stone Company is quarrying the Springfield beds, and the lower portion of Niagara, mainly for crushed stone. Sample 99, twenty-three feet in thickness, represents the Springfield bed. It is separated from the underlying blue limestone by a shale stratum of two feet six inches in thickness. The limestone carries some shale strata, but in general is a heavy and even-bedded hard blue stone. The section sampled was twenty-four feet, including the shale at top. This constituted sample 100. Sample 101 is fourteen feet in thickness;

it is a hard, silicious, calcareous shale, which appears like a stone, but which will not stand even summer weather without crumbling. It contains three layers of flint nodules in the first six feet, and one other further down.

The output of this quarry is very largely used for crushed stone.

The tables of analyses follow:

Leesburg samples.

Number of samples.	117	119	120	121	118
Description	J. F. Luft's quarry. Top, down 12 ft. Waterline formation.	Bank of Lees Creek. Top, down 10 ft. Yellowish stone underlain by 2 ft. shale.	Bank of Lees Creek. Next 6 ft. below shale. Darker than above.	Bank of Lees Creek. Next 13 ft. below 120. Blue, hard stone.	Bed of Lees Creek at anticline. Calcareous shale under blue stratum. 18 ft.
Silica	7.16	4.10	2.42	2.30	26.48
Alumina	2.19	1.32	0.78	0.95	7.36
Oxide of iron	1.05	1.10	1.78	1.55	1.10
Carbonate of calcium	49.95	52.63	53.70	53.63	35.65
Carbonate of magnesium	39.42	41.08	41.26	41.60	27.46
Totals	99.77	100.23	99.94	100.03	98.05

	Greenfield samples.			Hillsboro samples.		
Number of samples.	122	123	124	99	100	101
Description.	L. Helderberg. Top, down 31 ft. Massive layers.	L. Helderberg. Next 12 ft. below 122. Thin even beds.	L. Helderberg. Next 13 ft. below 123. Thicker even beds.	Top, down 23 ft. Cedarville formation.	Next 24 ft. below 99. Springfield formation.	Next 14 ft. below 100. West Union formation. (?)
Silica	1.10	1.90	2.10	1.88	9.88	30.12
Alumina	0.46	0.64	0.74	0.86	3.65	4.30
Oxide of iron	0.30	0.20	0.20	trace	0.45	0.80
Carbonate of calcium	55.00	54.00	53.70	54.10	50.90	40.20
Carbonate of magnesium	43.44	42.72	42.94	43.24	34.78	23.50
Totals	100.30	99.46	99.68	100.08	99.66	98.92

These analyses, while they add to our knowledge of these formations, do not disclose anything different from the results of the earlier Surveys, or anything modifying the belief that only dolomites, generally of high purity, may be expected in this county, and that its industries of building stone and white lime will continue to be the only uses for these great limestone beds.

HOCKING COUNTY.

This county has but one horizon of workable thickness for limestone. This is the Maxville formation, or Sub-Carboniferous limestone, lying just below the coal measures and on the top of the Logan sandstone. The limestones of the Pottsville formation, the lower and upper Mercer, and the Ferriferous, and Putnam Hill, while present in the east and southern portions of the county, are seldom over four feet in thickness, which is below the mineable limit, unless other material be taken out also, or the roof be exceptionally strong, as limestone mining in the solid requires heavy blasting, which shatters and breaks a weak roof.

The Maxville formation is a light colored, white or buff or gray stone, frequently of considerable thickness, but of very irregular deposition in Ohio. It seems to be eminently a pocket, or lake bed formation, as it can be found only here and there inside the area represented by its outermost deposits. When found, these different deposits manifest wide differences in composition, thickness and lithological structure, greater than would be apt to be the case in a continuous stratum in so short a distance.

The Maxville limestone has been used locally for lime, in a small way, but it is not now burnt for this purpose. Its chief employment in the past has been for furnace flux, for which some portions of it are highly suitable. Other portions are entirely unsuited.

The Maxville underlies (by supposition) but a small area in the center of Hocking county. Its southernmost known deposit is on the land of Culver Smith, two and one-half miles southeast of Logan, where a sample was taken by the writer.

The face of the stone here quarried was probably about fourteen feet. Ten to eleven feet were visible, but the earth had caved and obscured the bottom. The section cut was as follows:

		Inches.
	Shale	..
Sample 0-50	Solid bluish limestone	24
	Shelly limestone	27
	Iron ore stratum	3
	Solid buff limestone	12
	Shelly limestone	30
	Very solid, dense, conchoidal limestone, white or bluish white in color	36
	Bottom obscured	36
	Logan formation	..

No openings are known to have been made south of this one. Reports are heard of its being seen within a mile or so of Haydenville, but were not confirmed. On the east, it is not seen in the valley of Snow

Fork, being under drainage level. No records of its being met in drill holes in this section are on hand. On the west, it is practically certain that it is not met in any quantity beyond Logan. Inquiry in the country west of Union Furnace and near Ilesburgh, where it should be above drainage, failed to elicit any knowledge of exposures.

To the north, there is reason to believe that the stratum is more or less continuous, or that frequent pockets of it are formed. It has been worked for flux at various points along the Straitsville road, leading northeast from Logan, from a point two miles from Logan, nearly to Gore. The best known openings were at Winona, where it was used for flux for many years. No workings are now open, and no new samples were taken.

The following analyses of this stone are all that can be given:

Analysis of Maxville Limestone.

Analyst.	Peppel.	Lord.	
Description.	Section of vein, 14 ft. thick, on Smith farm, near Logan. Sample 0-50.	Average of three different analyses of top stratum of vein at Winona.	Single analysis of the bottom stratum at Winona.
Silica	8.16	5.45	12.1
Alumina	2.42	5.60	0.45
Oxide of iron	2.80		
Carbonate of calcium	77.45	56.30	86.9
Carbonate of magnesium	9.40	32.40	0.8
Totals	100.23	99.75	100.25

The wavering, unstable character of the deposits may be judged from the foregoing. The last analysis represents material especially suited to the portland cement business, if suitable quantity were available and cheap mining or quarrying could be had. But the facts, so far as known, do not indicate that the whole stratum would be more than sufficient, and certainly the removal of a highly magnesium cap rock as indicated in the second analysis would reduce the value of the deposit very greatly. The best that can be said, then, on the availability of the Maxville for a portland cement proposition in Hocking county, is that there are exposures of the stone of exceptionally favorable composition, but insufficient quantity, and that the finding of other deposits of sufficient quantity and sufficient purity are not improbable.

The lower Mercer stone, at Union Furnace, has a thickness of four to five feet. It is underlaid by a thin coal and a valuable clay, now extensively worked by mining. Many thousands of tons of this limestone are now undercut by the removal of eight to twelve feet of clay, and could be blasted down and loaded at relatively small expense.

The composition as reported by Wormley (1870) is:

	Per cents.
Silica	36.89
Alumina and iron	9.20
Carbonate of calcium	52.60
Carbonate of magnesium	1.21
Total	99.90

This analysis does not represent the average quality of this stone, which has been analyzed by several different chemists for private purposes, with results materially lower in silica and alumina, and higher in calcium, but still low in magnesium. There is not enough of it to form the basis of a large industry, though a small cement plant could undoubtedly work it in connection with its coal vein.

The Ferriferous limestone, a valuable material to the south of Hocking county, is here on its feather edge, disappearing, and is of no value.

HOLMES COUNTY.

Holmes county, though nominally lying almost wholly in the coal measures, is nevertheless possessed of but little stratigraphical range. The rocks apparently drift to the southeast very gradually, for even on the eastern edge of the county, the middle Kittanning coal is rather high in the hills, and the top of the Allegheny represents about the highest formation reached, while on the west, the bottom of the Pottsville makes the body of the hills, and only the deeper valleys reach the underlying sandstones of the Logan and Black Hand formations.

The limestones encountered in this range comprise the lower and upper Mercer, the Ferriferous and Putnam Hill, and possibly the Freeport in the southeastern corner. None of them have become the basis of any lime or quarry industries so far as is known. None of them are thick either here or in the surrounding country; only one has attracted the attention of the geologists who have worked in this field. This is the Ferriferous in the vicinity of Millersburg. Its exact location or thickness are not given, but the deposits have attracted attention from two observers, for the following analyses have been filed:

Ferriferous Limestone from Holmes County.

Analyst.	Wormley—1870	Lord—1884.
Silica	7.10	2.90
Alumina and iron oxide	1.00	2.71
Carbonate of calcium	86.60	92.02
Carbonate of magnesium	1.89	1.85
Combined water	1.45	....
Total	98.04	99.48

These analyses indicate an excellent material for cement, if they correctly indicate the average composition of a large body of material, but this is not believed to be the case. Certainly the burden of proof lies on the investor, who must locate and define his deposit before it is of value.

JACKSON COUNTY.

Jackson county is situated just on the borders of the coal measures, its western valleys cutting into the Logan and Black Hand formations, while the eastern hills are topped with the Freeport coals and limestones.

The limestone strata represented are the two Mercers, the Ferriferous and the Freeport. The Maxville has never been found. The first and last are economically unimportant, being thin and unworkable. The Ferriferous, which is thinning down on the north as it passes into Vinton county, is still a persistent and valuable stratum in the northern townships of Jackson, and throughout the rest of the county it presents one of its best phases.

The stone in this district is a dense, solid stratum varying from four feet on thin exposures in the north and west, to sections represented to be ten feet in the south and east. The writer has never seen this stone at a point where it measured over eight feet six inches. It does not split well into building stone. Its fracture is earthy or conchoidal, instead of crystalline, and it does not work well. It produces a hot lime, and while it has been used locally, it has never been extensively put on the market. Its uses in 1870, when first examined, were almost wholly for furnace flux, for which it is excellently adapted.

Since that time, a portland cement industry has been established at Wellston, on this limestone as a basis. There are four plants built, or building, in the county, and others in Lawrence county adjoining. The plants were first supplied chiefly from small quarries, located at various points where the stone lay in good thickness and accessible. As the demands have grown, the companies have established their own workings for limestone. The stone up to 1903 was won entirely by stripping and benching around the edge of the hill; in fact, in Jackson county the stone lies too near the top of the hills in most of the areas to be won by mining operations. The blasting required to bring it down requires an excellent solid roof, and no shallow mining is possible.

The composition of this stone cannot be adequately shown from the analyses of the Survey in this county. It has been analyzed on a large scale by the chemists of the cement plant, who find the carbonate of calcium running from 88 to 94 per cent., averaging 90, while the magnesia runs from 0.50 to 3.00, averaging 1.50 per cent. The following analyses are available:

Analyst.	Wormley.			Peppel.	Nauss.
Description.	Blue limestone from Star furnace, said to be "Putnam Hill."	Ferriferous limestone, Star furnace, upper part of vein.	Ferriferous limestone, Star furnace, lower part of vein.	Ferriferous limestone, Kitchen station. Cross section 7 ft. 6 in. including flint vein.	Ferriferous limestone from Cornelia furnace. Alma Cement Works.
Silica	1.00	1.00	5.40	13.62	3.00
Alumina and oxide of iron	6.80	1.00	2.00	2.45	3.48
Carbonate of calcium	88.80	94.20	88.00	82.30	91.04
Carbonate of magnesium	1.20	0.76	1.51	0.82	1.30
Water, combined	1.80	2.90	2.90	....	....
Totals	99.60	99.86	99.81	99.19	98.82

The sample from Kitchen station does not represent the purity which can easily be obtained. The quarry had been opened out to supply stone to the cement plant, but after getting well under way, a flint vein appeared in the stone, increasing until finally three to four feet out of seven feet six inches were affected.

Separate samples of the top, middle and bottom strata were made with the following analytical results. (Nauss.)

Harrison's Limestone—Kitchen Station.

Number of samples.	15	17	16
Description of sample.	Top 18 in. of vein. Pure, free from flint.	Middle 42 in. of vein. Flinty.	Bottom 18 in. of vein. Pure, free from flint.
Silica	0.72	22.91	0.78
Alumina and oxide of iron	1.97	2.05	1.41
Carbonate of calcium	96.00	73.40	95.54
Carbonate of magnesium	0.54	0.64	0.68
Totals	99.23	99.00	98.41

When this change in composition took place, the cement plant refused to accept the flinty material—very justly under some circumstances, but apparently under the apprehension that all silicious material is bad, an assumption which seems to the writer fundamentally wrong. The use of a silicious limestone, whose silica is amorphous and intimately mixed in the rock itself, seems to the writer most desirable, and has merits far and away above the addition of sandy clays to supply the needed silica, because the clays almost invariably bring in too much alumina as well. Of course, the rock must be uniform, not high in silica today and low tomorrow. But the rejection of silicious stones, per se, does not seem technically a well advised plan.

The situation of Jackson county and Lawrence county, in which lies practically the whole of this formation of workable thickness, is so nearly identical, that further discussion of these problems of utilizing this limestone will be discussed in connection with the district as a whole, elsewhere in this report.

(See also Lawrence county).

JEFFERSON COUNTY.

This county lies in the upper portion of the coal measures. On the north edge, the valleys of the Ohio and Yellow creek cut down into rocks of the Allegheny formations, about to the lower Kittanning. But toward the south, the strata dip steadily, so that on the southern portion the valleys cut down into the Conemaugh, while the Pittsburg coal is everywhere above drainage and the hill tops reach the Upper Barren measures or Dunkard formation.

The area of the Pittsburg coal marks the area of limestones of commercial promise. The northern and western portions of the county are excluded from consideration, as the Pittsburg coal is not importane north of the line of the P. C. C. & St. L. R. R. South of that line, the limestones of the Upper Measures, desribed in Belmont county, are found well represented.

No samples of these formations were taken in southern Jefferson county. The last sample in Belmont county lay just on the county line, and will answer for both. At Steubenville, a sample was cut at a point about two miles southwest of town, from a vein twelve feet thick and located about twenty to twenty-five feet below the Pittsburg coal, and fifty to sixty feet above the Crinoidal limestone. This vein has not been sampled elsewhere, in just this stratigraphical position. The area of good stone on this horizon is not thought to be large. The analysis is by Mr. Peppel.

		Per cent.
Sample 176	Silica	12.50
	Alumina	10.11
	Oxide of iron	4.19
	Carbonate of calcium	61.10
	Carbonate of magnesium	5.86
	Total	93.76

This does not appear favorable to the cement industry, and still less so to any other.

LAWRENCE COUNTY.

The coal measures cover all parts of this district. The formations range from the lower Mercer limestone or a little below, along the western frontier, to the Pittsburg coal along the eastern edge.

The lowest limestone, the lower Mercer, appears in workable thickness a mile or so beyond the Lawrence county line, at Howard Furnace. Doubtless other exposures of this stone above drainage could be found. This limestone, or the Maxville, was encountered at Olive Furnace in a bore hole, two hundred feet beneath the surface. The core removed was almost white, exceedingly dense, and a very pure carbonate of lime. The thickness was reported about twelve feet.

The next and most important limestone horizon is the Ferriferous. This formation extends in a belt about six or eight miles wide, from north to south across the county, taking in Washington, Decatur, Elizabeth, and Hamilton townships in full, and occurring also in the western portions of Perry, Lawrence, Aid and Symmes townships.

It lies generally upon the Clarion coal, but the latter was cut out or never formed over large areas in which the limestone persists. Its thickness runs from six feet at the thinner exposures up to eight feet six inches at the highest measured section, though ten feet are reported at places. It is a good, strong, gray stone, inclining to the conchoidal in fracture, and generally not well bedded, so that it breaks massive in quarrying. Its composition is singularly uniform and a very pure high-calcium stone, consistently low in magnesia. The silica fluctuates somewhat, as a little flint comes in from time to time, but it averages less than four per cent.

Great numbers of analyses of this stone are available, as it has been used for many years for blast furnace flux and has been quarried at many points. A collection of such analyses is given in the following table:

Ferriferous Limestone—Lawrence County.

Description of sample.	California Hollow. Upper township. Hecla Iron Co.	Burke's Mine. Elizabeth township.	Holly's Mine. Elizabeth township.	Riley's mine. Elizabeth township.	Hanging Rock, from books of Hanging Rock Iron Co.	Burgess Tract. H. R. I. Co. Average of 10 analyses.	Bradshaw Entry. H. R. I. Co.	School House Entry. H. R. I. Co.	Hog Run, Section 25.	Peter Cave Hollow. Mines of E. B. Willard.	Pine Grove Furnace. Hanging Rock Iron Co.	H. Campbell & Son. Analysis by Lord.
Silicious matter	0.98	0.41	1.30	0.52	0.76	3.30	0.76	1.10	1.96	0.26	1.00	1.67
Alumina	2.15	0.86	0.86	0.80	.....	6.20	1.50	3.20	.....	0.50	1.00	1.36
Oxide of iron		0.78	.....	.....	.....			5.25	1.98	1.30	2.00	
Carbonate of calcium	94.65	93.28	.....	94.19	96.87	88.50	96.83	88.70	91.32	96.83	94.30	95.40
Carbonate of magnesium	1.84	4.66	3.81	4.49	.....	0.75	0.84	1.60	0.91	1.00	1.53	1.38
Totals	99.62	99.99	.....	100.00	.....	98.75	99.93	99.85	96.17	99.89	99.83	99.81

The high and maintained proportion of lime in this list of analyses is significant. The formation is evidently more nearly homogeneous chemically than any yet considered.

As these samples represented all kinds of sampling, as well as the work of a number of different chemists, and a number of different dates, it was decided to make a few analyses for the Survey with the present method of sampling. The results are given as follows:

Number of samples.	0-33	0-35	0-37	0-38
Description of samples.	Olive furnace. 6 ft. 9 in., no flint.	Burke's mine, Bartle's station 7 ft. 6 in.	Willard's mine, Steece P. O., 6 ft. 6 in.	Fine crushed stone taken from beneath crusher. Willard's mine, Steece P. O.
Silica	1.52	0.74	3.26	22.26
Alumina	1.86	0.24	0.90	1.05
Oxide of iron	0.70	1.30	1.30	1.55
Carbonate of calcium	95.40	97.35	94.16	75.07
Carbonate of magnesium	0.53	0.33	0.85	0.20
Totals	100.01	99.96	100.47	100.13

The results of the Survey's sampling are not found to materially differ from the collected analyses made for the furnace companies; this is a further endorsement of the uniform character of the formation.

This stone is most eminently suited to portland cement manufacture. It has already attracted one company to Ironton, and without doubt others will follow. Its use for no other purpose is so apt. The lime made by the burning of this stone is gray or brown, and very hot and violent, which will preclude its extensive use in that field, unless it be used for sand brick manufacture.

The suitability of the stone for Portland cement, from the chemical standpoint, requires also consideration of its availability from the commercial standpoint. As the considerations which apply to this county also apply to the field as a whole, they will be given in the succeeding chapter, under the head of the Ferriferous limestone.

The limestones of the upper coals are formed in the eastern side of the county. They are usually thin and worthless. At the head of Cannon's creek, in Aid township, the Cambridge stone thickens up locally and is quarried for road metal. It is very cherty at this point, and by itself would be useless for any chemical purpose, but its possible use in diluting the very rich hot limes of the Ferriferous horizon, and as a means of introducing silica without also adding alumina to the mixture, was considered. A sample was cut, cross-sectioning the vein, and analyzed by Mr. Peppel.

Cambridge Limestone from Cannon's Creek.

		Per cent.
Sample 0–40	Silica	38.00
	Alumina	6.78
	Oxide of iron	1.90
	Carbonate of calcium	50.60
	Carbonate of magnesium	1.73
	Totals	99.01

If this formation is found to have any wide extent in this or greater thickness, it should be a valuable means of control for cement makers.

LICKING COUNTY.

In the eastern end of Licking county, the Carboniferous formations come in, especially in Bowling Green, Franklin and Hopewell townships. In this vicinity, the Maxville limestone is due and is reported to have been found and worked for road metal in 1832 and 1835, for construction of the National road to Columbus. Whether these old quarries came into Licking county is not known, but in any case they are not believed to represent a thick or important extension of the Maxville field. Nothing can be found of this formation in the gorge of the Licking river, eight or nine miles north.

The Mercer limestones are generally thin and unimportant, but in some points in these same townships it thickens up in local basins. One of these on the land of William Gordon, three miles northwest of Brownsville, in Hopewell township was sampled by the writer. The section presented was as follows:

		Feet.	Inches.
	Shales	..	..
	Iron ore, in kidneys	0	4
	Yellow flint	0	6
Sample 0–59 12 ft.6 in.,	Blue shelly limestone	9	0
	Shale	0	6
	Hard blue limestone	2	0
	Coal	1	0
	Fireclay	..	..

The analysis of this stone, by Mr. Peppel, gave the following:

	Per cents.
Silica	44.64
Alumina	6.78
Oxide of iron	2.20
Carbonate of calcium	43.18
Carbonate of magnesium	1.09
Total	97.89

Exclusion of the shale would materially improve the lime content of this stone. It would be an admirable means of introducing chemically-active silica into a portland cement mixture composed of high calcium stone.

While no other outcrop equal to this in thickness was found, it is entirely likely that others exist. No limestones higher than the Putnam Hill are believed to occur anywhere in this vicinity, and none of this formation was found of workable thickness.

LOGAN COUNTY.

Three limestone formations are present in this county. On the west, is a large corner of Niagara. The Waterlime covers the rest of the county to the east, and superposed on this occurs a considerable island or patch of Corniferous, which occupies the crest of the Cincinnati anticline. The Corniferous is in turn capped by two smaller islands of black shale which prevent access to it except around its edges. The drainage has cut through both Corniferous and Waterlime in places exposing more or less of both.

The Corniferous has been quarried for stone, and burned for lime, around the edges of its area in many places. The Waterlime has similarly been opened in many points. The stone and lime industry has never been very large, but has more than supplied the need of its own immediate locality.

The present quarries of the Bellefontaine Stone and Lime Company are located west of Bellefontaine, probably in the Waterlime formation. Mr. Peppel gives the following concerning three samples:

"The stripping here is from four to eight feet. The top stone of the quarry is a close-grained gray rock, finely crystalline, and almost earthy in appearance, somewhat like the stone of the Marble Cliff quarries, west of Columbus, in lithological character. This stratum was eight feet in thickness and constitutes sample 37. The next four feet is a rotten stone, consisting of alternate soft and hard layers, so that it does not work well. This constitutes sample 38. The lower fifteen feet is composed of finely crystalline gray stone in beds of eight to thirty inches in thickness. This course is quite soft when first taken from the quarry, and may be carved easily, but soon becomes very hard on exposure to air. This stratum constitutes sample 39. This company has several openings close together, one being worked for building stone, and another for crushed stone. It is claimed that there is only about ten per cent. waste in quarrying the building stone."

The older reports give the Scarf quarry at Bellefontaine as Corniferous, while Mr. Peppel characterizes the present workings as Lower Helderberg. It is probable that the workings are in the same horizon and that it is Lower Helderberg, as the analyses show all to be purely dolomitic, while the Corniferous in its nearest manifestations is low-magnesia, high-calcium material. The analyses follow:

Analyses of Bellefontaine Limestone.

Analyst.	Wormley.		Peppel.		
Number of sample.	—	—	37	38	39
Description of sample.	Scarf's quarry.	Scarf's quarry.	Top, 8 ft. down. Grey, hard, well bedded.	Next 4 ft. below No. 37. Soft and rotten.	Next 15 ft. below No. 38. Soft, becoming hard in air. Heavy bedding.
Silica	2.80	2.70	2.00	1.24	2.10
Alumina	1.30	2.10	0.96	0.21	0.99
Oxide of iron			0.20	0.35	0.15
Carbonate of calcium	55.10	55.00	54.70	55.30	54.40
Carbonate of magnesium	40.11	39.74	42.80	43.17	42.92
Totals	99.31	99.54	100.66	100.27	100.56

No evidence is at hand from thoroughly known Corniferous samples, as to the composition of these strata in this county. The above are excellent dolomites and would make white lime, but are worthless for cement manufacture.

LUCAS COUNTY.

Save for a narrow band of black shale on the western edge, Lucas county is covered with limestone strata, the Corniferous occupying a band about five miles wide and running nearly north and south, on the west, while the Waterlime is the superficial rock on the east. A narrow band of Niagara crosses this Waterlime, north and south through Oregon township, but as the stones are of similar composition, the effect on the lime industry is small.

The stone industry has never been prominently developed in this county. The extreme flatness of the topography has made the quarries difficult to drain, and often heavily buried with drift, thus not inviting working. Nevertheless, there have been a number of openings made. At present, there are quarries at White House, Sylvania, and Holland, chiefly producing crushed stone.

The old reports are almost silent on the composition of the limestones of this area. The only analyses made were those in 1870 by Dr. Wormley. The samples were credited to Toledo, but were probably selected at quarries in that vicinity, but not in the city. They were selected from the Waterlime formation, to demonstrate that this formation really was capable of furnishing stones capable of the making of hydraulic lime, which its name implies. No details of the samples were given.

The recent work was confined to a test of the Corniferous, which has not been previously tested in this district. Mr. Peppel's remarks follow:

"The Corniferous was sampled at the quarry of John Pray at White House. The top seven feet of this quarry is a hard, gray, crystalline limestone, highly fossiliferous, represented by sample No. 22. It probably composes the extra cap rock of the same formation at Kelley's Island and Marblehead, mentioned in Dr. Orton's report of 1888. No. 23 is the next seven feet below, an even-bedded limestone with few fossils. This stratum rests on a bed of flint nodules, which in turn overlies a heavy bed of stone. This compares well with the stone at Delaware, except that it is not so dark in color."

The analyses follow:

Analyses of Lucas County Limestones.

Formation.	Waterlime.			Corniferous.	
Analyst.	Wormley.			Peppel.	
Number of Sample.	1	2	3	22	23
Description.	Selected as representing hydraulic lime, Toledo.	Selected as representing hydraulic lime, Toledo.	Selected as representing hydraulic lime, Toledo.	Top, down 7 ft. Pray quarry, White House.	Next 7 ft. below No. 22, Pray quarry, White House.
Silica	16.76	19.40	5.00	1.24	1.66
Alumina	2.24	1.82	1.60	0.69	0.96
Oxide of iron				0.05	trace
Carbonate of calcium	46.60	44.40	52.80	95.25	74.52
Carbonate of magnesium	32.69	32.69	39.65	3.47	23.50
Totals	98.29	98.31	99.05	100.70	100.64

The Waterlime samples were probably flinty, as the silica alone is high. The alumina and iron are not above the average, and the lime-magnesia ratio is dolomitic, indicating mere dilution of a dolomite with extra silica. There is an abundance of limestone in this formation in this county which will analyze as pure a dolomite as can be found anywhere in the formation.

The Corniferous samples show at once the differences in the formations. Just what part of the Corniferous is here represented is not clearly proven, but Mr. Peppel's hypothesis of the Delaware formation is strongly supported by the comparison of analyses of the two districts.

The upper bed of the Corniferous here is one of the pure limes of the state, and should be of interest to Michigan cement and sugar industries, where high-lime and low-magnesia stone is essential.

MAHONING COUNTY.

Carboniferous rocks are superficial in this whole territory, but the flat topography and gentle slope make only a small vertical section obtainable. The Pottsville formation forms the floor on the north; coal No. 1, at the bottom of the coal measures, was found in pockets around Youngstown and exhausted long ago. On the southern edge of the county, the hill tops reach the Kittanning or possibly the Lower Freeport horizons.

The limestone strata of economic importance are confined to one horizon, the Ferriferous. The Maxville is missing, the Mercers are small and of importance only in tracing other strata. The Ferriferous is not a persistent or uniform deposit, but does occur in good volume in several points, especially on the eastern edge of the county near Lowellville.

The Ferriferous has been extensively quarried in this vicinity for furnace flux for many years. Other points have contributed some limestone also, but the main dependence of the extensive iron industry of this region has been the Lowellville stone. The following analyses have been collected, in addition to the two new ones made by Mr. Peppel.

Ferriferous Limestones from Mahoning County.

Locality.	Green township	Lowellville and vicinity.				
Analyst.	W. A. Hooker.	W. A. Hooker.	F. N. Holbrook.	Lord.	Peppel.	
Description of samples.	From Goodman's quarry.	From J. Moore's quarry.	From J. Moore's quarry.	Lowellville limestone.	South of Lowellville; top, down 14 ft. 6 in., sample 180.	Sample 179, next 4 ft. 6 in. below sample 180.
Silica	1.61	11.00	2.08	3.24	2.58	2.20
Alumina	2.55	4.39	1.33	2.26	0.68	0.54
Oxide of iron					0.70	0.70
Carbonate of calcium	91.86	80.43	95.58	93.24	93.50	94.69
Carbonate of magnesium	0.59	2.29	1.30	2:19	1.64	0.71
Organic matter and water	3.45	2.25	0.06	....	....	....
Totals	100.06	100.36	100.35	100.93	99.10	98.84

It is seen that Mr. Peppel's carefully averaged cross sections do not depart widely from the analyses made from the samples formerly taken.

All agree in showing this limestone to be of most excellent quality for portland cement, even the silicious ones. Mr. Peppel says that there are only a few square miles of this limestone to be found on the Ohio side of the line. The thickness at the point sampled, nineteen feet, is exceptional, but fourteen and fifteen feet is commonly mentioned in the older reports. There was formerly some question as to the horizon of this stone, some calling it Freeport. It is undoubtedly Ferriferous.

MARION COUNTY.

Marion county is essentially a limestone county. Only a small amount of territory on the east is covered with shale. The formations are Corniferous on the east and Waterlime on the west, with a very small corner of Niagara on the northwest.

The quarry industries are prominent at Marion and at Owens station. At both points, large and old quarries are developed, both shipping lime, crushed stone, furnace flux and building stone. The Marion quarries are using the top or blue Delaware beds exclusively for crushed rock or building stone. The top of the Columbus, called the "cap rock," is reserved for furnace flux, almost exclusively. The bottom stratum, which is the middle or main body of the Columbus formation, is used for lime burning. The two analyses by Professor N. W. Lord, given herewith from Marion, are quoted from the older reports:

Description of samples.	Top of Columbus formation. Flux stone. Average of three analyses.	Middle and lower Columbus formation used for lime burning.
Silica	3.50	1.60
Alumina and oxide of iron	0.50	0.24
Carbonate of calcium	79.01	66.02
Carbonate of magnesium	16.85	33.10
Totals	99.86	100.96

These analyses show wide divergence from the composition of the corresponding strata at the Columbus quarries. The formation, while not a dolomite, has increased enormously in its magnesia content, and thereby becomes less differentiated from the Waterlime which underlies it.

At Owens station, six miles south, the quarries have been carefully studied by three observers, Dr. Orton, Professor N. W. Lord, and Mr. Peppel. The results of each are given herewith.

Dr. Orton places the formational range of this quarry as follows:

	Feet.
Lower half of Delaware bed	15
Flux stone (top of Columbus)	20
Limerock (lower Columbus)	5

He says that going down further would bring Owens into the same beds now used at Marion for lime burning, of which he now is only using a little.

Professor N. W. Lord made a careful section of these strata in 1887 for a private company, which was published by permission in Vol. 6, p. 769, and which is here reproduced.

Owens Limestones, Lord.

Number of samples.	8	7	6	5	4	3	2	1
Description of samples.	Top, down 3 ft. Flux stone.	From 3 ft. to 6 ft. Flux stone.	From 6 ft. to 9 ft. Flux stone.	From 9 ft. to 11 ft. 6 in. Flux stone.	From 11 ft. 6 in. to 15 ft. 6 in. Flux stone.	From 15 ft. 6 in. to 19 ft. 6 in. Fluxstone.	From 19 ft. 6 in. to 23 ft. Limestone.	From 23 ft. to 25 ft. 6 in. Limestone.
Silicious matter	3.20	4.60	2.92	1.35	1.57	1.92	2.20	1.65
Alumina and oxide of iron.	4.00	1.25	4.33	6.01	3.05	1.85	1.97	2.65
Carbonate of calcium.	88.30	80.40	84.70	92.00	85.55	74.00	66.15	72.85
Carbonate of magnesium.	2.58	13.80	8.64	0.56	10.39	21.46	27.97	22.38
Totals	98.08	100.05	100.59	99.92	100.56	99.23	98.29	99.53

Dr. Orton correlates Nos. 8 to 3 as the cap stone or flux-stone or upper portion of the Columbus formation, while the blue Delaware beds, which he describes here as being worked for building stone and crushed rock, lie upon these and were not sampled in the Lord section.

The limestone at the bottom comes from the center or lower portion of the Columbus formation.

Mr. Peppel's observations are as follows:

"The stripping at Owens station is light, as also at Marion. Sample No. 9 at Owens is a blue limestone, carrying a few courses of flint nodules. This stone is used for building and crushed stone. It is probably the Delaware stone. No. 8 and all below No. 7 is gray limestone, and is used for both flux and lime burning. No. 7 is of a browner color and is called "bastard" rock and used for crushed stone, probably because it is higher in phosphoric acid than the stone used for flux rock. Reference to the analysis shows its other impurities are not sufficient to condemn it for flux, though it is not quite as good as No. 8. This course is very persistent through the Columbus phase of the Corniferous, and is usually found over a flint bed and about ten to fourteen feet from the top of the Columbus formation. It is twenty-eight feet from the bottom of No. 7 to the Lower Helderberg, and with the exception of the last six or seven feet, it is all rather high in carbonate of calcium—probably seventy per cent. or more."

Owens Limestones, Peppel.

Number of samples.	9	8	7
Description of samples.	Delaware formation. Blue rock for building and crushing. Top, 19 ft. down.	"Cap Rock," for flux. Top of Columbus form. Next 10 ft. 6 in. below 9.	Lime rock. Middle of Columbus form. Next 3 ft. 6 in. below 8.
Silica	12.50	2.32	3.42
Alumina	2.05	0.90	1.02
Oxide of iron	0.25	trace	trace
Carbonate of calcium	64.00	88.37	70.15
Carbonate of magnesium	20.47	8.38	26.21
Totals	99.27	99.97	100.80

These sections do not exactly correspond with Professor Lord's, who did not examine the Delaware formation at all. The comparison as nearly as can be made is as follows:

Observer.	Lord.	Peppel.
Delaware formation.	....	64.00 $CaCO_3$ 20.47 $MgCO_3$
Top of Columbus formation. "Cap rock," or flux stone.	19 feet thick. Average.....84.16 $CaCO_3$ 9.57 $MgCO_3$	10 feet, 6 inches thick. 88.37 $CaCO_3$ 8.38 $MgCO_3$
Middle Columbus formation. Lime rock	6 feet thick. Average.....69.50 $CaCO_3$ 25.17 $MgCO_3$	3 feet, 6 inches thick. 70.15 $CaCO_3$ 26.21 $MgCO_3$

Thus the concurrence between these two chemists in reaching the average composition of a thick mineral vein is very close, though the work was done years apart and with different purposes in view. The agreement in the constitution of cap rock and lime rock between Marion and Owens station is also fairly close.

In summing up, it may be said that the Corniferous formation in Marion county, while probably containing thin strata of high-calcium low-magnesium stone here and there, does not give promise of showing any large bodies of it which could be quarried without providing for the disposition of much other rock. It does not offer as attractive a prospect for cement manufacture as other phases of the Corniferous. For white lime, building stone, flux and crushed rock, its reputation is already well established.

No quarries in the Waterlime in this county could be found at present.

MERCER COUNTY.

Practically the whole of this county lies in the Niagara formation. Its low, flat topography and heavy drift are unfavorable to quarrying operations. Openings have been made at many points, but they were shallow and usually temporary and merely supplied the local demand for the time being. The white limes from Sandusky and other points come in by rail at a price which has almost destroyed the small beginnings of the quarry industry.

The only analysis of the stone of the Niagara from this district is from a sample taken by Mr. Peppel at a point about four and one-half miles west of Celina, in Jefferson township, where a knoll of limestone comes to the surface, surrounded on all sides by heavy drift. One-half mile east, it is forty feet to the rock, and one and one-half miles west it is sixty feet, while one mile north it is seventy feet down to solid rock. Four feet only could be sampled. The results follow:

		Per cent.
Sample No. 30	Silica	1.14
	Alumina	0.52
	Oxide of iron	no trace
	Carbonate of calcium	54.80
	Carbonate of magnesium	43.10
	Total	99.56

This shows that the stone retains here its characteristic excellence for white lime.

MIAMI COUNTY.

The Niagara formation covers this county except along the valleys of the Miami and Stillwater creek, which have cut their way down into the Clinton. This narrow band of Clinton runs up Stillwater to the center of Newton township, and up Miami river to Piqua. There is also a small area of Clinton southeast of Troy, chiefly in the north edge of Bethel township.

Important quarries have been located at Covington in the northwestern corner of the county, and at Piqua; in both, the production of building and crushed stone has been paramount, though lime has been and is still burnt at both points.

The analyses made for the earlier work of the Survey comprise:

Formation.	Niagara.		Clinton.	
Analyst.	Lord.		Lord.	Wormley.
Description of samples.	Rhule's quarry, Covington.	Corey quarry, Brant.	Harrington farm, Near Piqua.	Smith's quarry, Ludlow Falls.
Silica	0.85	0.32	0.45	0.80
Alumina Oxide of iron	0.40	0.40	0.26	1.20
Carbonate of calcium	54.14	54.80	95.03	91.30
Carbonate of magnesium	44.90	44.01	4.35	6.51
Totals	100.29	99.53	100.09	99.81

The Niagara is seen to be the usual pure dolomite, not surpassed in quality anywhere. The Clinton shows in these two analyses a phase similar to that of New Carlisle, a very pure high-calcium lime. An effort was again made to see whether these analyses represent their formations, or whether they are merely unusually favorable samples of small size.

Mr. Peppel looked into the question by sampling the Clinton and the overlying Niagara at Piqua by accurate cross-sections of the strata. Of these he says:

"The Clinton samples from Piqua were from the quarry owned and operated by the Ohio Marble Company. There is an abundance of this formation exposed on the east side of the Miami, with very little stripping. Sample 43 was composed of the top eight feet of the Clinton. Sample 36 was the next fourteen feet four inches below sample 43.

In the quarries of the D. C. Statler Company across the river, sample 44 was cut from the Niagara which rests on the Clinton. It is an even-bedded, hard, light-blue stone, with some iron pyrites in it. Analyses of this stone by different layers shows a range of composition from 97 per cent carbonate of calcium with one per cent. carbonate of magnesium to 69.64 per cent. carbonate of calcium and 25.20 per cent. carbonate of magnesium.

At Ludlow Falls, the following persons are working the Lower Niagara in a small way for building stone, viz:

The Maxwell Stone Company,
James Kropp & Company,
Ehler and Bukholder,
F. M. Coppock.

A sample of the formation was taken here, but unfortunately, it was lost in transit."

The analyses obtained are as follows:

Piqua Limestones.

Number of samples.	44	43	36
Description of samples.	Niagara formation 16 ft. 6 in. just above Clinton. D. C. Statler quarry.	Clinton formation. Top, down 8 ft. Ohio Marble Co.	Clinton formation. Next 6 ft. 4 in. below No. 43. Ohio Marble Co.
Silica	6.24	1.40	0.46
Alumina	2.52	1.14	0.59
Oxide of iron	1.00	trace	0.17
Carbonate of calcium	59.40	87.50	82.35
Carbonate of magnesium	31.04	9.40	16.76
Totals	100.20	99.44	100.33

These results show the Niagara at a poorer phase than usual, but still strongly dolomitic. The Clinton, on the other hand, does not hold up to its former figures by a large amount. In its phase shown in these analyses, it is of no special interest in the chemical industries, and is entitled only to what value it may have for building, crushing, or white lime. Of the latter, it would make a hot variety. The Clinton at this point is ground, and largely used for marble dust for various purposes.

MONROE COUNTY.

The strata of this county are among the highest, stratigraphically considered, of the state. The Pittsburg coal is everywhere below drainage, and the limestones between the Meigs Creek and Pittsburgh are above drainage in only a few square miles in the northeast corner of the county. The Meigs Creek coal is above drainage in the northeast and southwest, but a broad band crosses the county from northwest to southeast, which is above this formation and so far as is known is barren of all limestone or coal. The only limestone beds of consequence are those lying above the Meigs Creek coal.

No previous work having been reported from this county on this subject, samples were taken at suitable geographical range. Mr. Peppel's observations are as follows:

"A sample, No. 169, was taken at a point on the B. Z. & C. R. R., one mile southwest of Coats station. A section of the hill at this point is as follows:

		Feet.	Inches.
	Heavy sandstone ledge	..	..
	Interval	40-50	..
	Buff limestone (one bed)	4	0
Sample 169 11 ft. thick	Buff limestone (two beds)	3	0
	Brown, laminated shaly limestone	2	0
	Shale	0	6
	Buff limestone	0	6
	Hard blue limestone	1	6
	Shale	0	2-6
	Limestone in uneven beds with shale partings	4	0
	Brown shale, like a coal blossom	..	..
	Sandstone	..	..

"The following section is characteristic of west-central Monroe county.

	Feet.
Hard blue limestone	5
Shale	10
Buff limestone	7
Shale	20
Blue limestone	4-5

"The buff limestone is close to drainage at Dexter city.

"Sample 152 was found on north bank of Little Muskingum, near Mechanicsburg. This consisted of an earthy, yellow, rotten limestone, six feet thick. This sample carries one six inch and one nine inch bed of shale.

Sample No. 151 came from Quarry P. O., section 6, Bethel township, about three-quarters of a mile north of Washington county line. The stone is light buff in color, earthy in texture and conchoidal in fracture. It weathers yellow in color, and breaks up into small pieces, but does not slake into an earthy mass. The strata at this point are as follows:

		Feet.	Inches.
	Red shale	..	..
	Limestone (roof)	1	6
Sample 151	Buff limestone	5	0
	Limestone in beds 2 to 3 inches thick	2 3	..
	Shale	0	4
	Limestone	2	0

"The following section was sampled one mile west of Stringtown (Fly P. O.) in the extreme southeast corner of the county:

		Feet.	Inches.
	Sandstone	..	..
	Sandy shale	..	..
	Sandy limestone (roof)	..	..
Sample 183 11 ft.6 in.	Green shale	0	8
	Hard blue limestone	1	4
	Blue shale	1	6
	Hard red shale	1	0
	Limestone, blue tending to buff	2	6
	Hard green shale	2	0
	Green limestone, impure	1	0
	Hard blue limestone	..	..
	Sandy shale	2	6
	Green shale	2–3	0
	Limestone	0	6
	Drainage level	..	..

The analyses of these samples follow:

Number of samples.	169	152	151	183
Description of samples.	Coats station. 11 ft., mainly buff limestone.	Mechanicsburg, 6 ft., limestone and shale partings.	Quarry P. O., 7 ft., limestone and shale partings.	Fly P. O., 11 ft. 6 in. limestone with much shale.
Silica	15.20	23.53	14.92	26.48
Alumina	5.02	7.77	3.83	7.28
Oxide of iron	1.30	2.79	2.47	2.30
Carbonate of calcium	55.80	40.79	47.85	50.50
Carbonate of magnesium	21.16	23.71	30.41	10.75
Totals	98.48	98.59	99.48	97.31

These results clearly establish that nothing is to be expected from the buff limestones, lying above the Meigs Creek coal in this vicinity, so far as portland cement is concerned. They are, however, pretty well suited to roman cement of the Louisville type, so far as composition is concerned. Whether they would become the basis of a successful industry under present conditions is doubtful, in view of the history of the Barnesville and Bellaire plants.

MONTGOMERY COUNTY.

This district lies on the dividing line between the Hudson River group and the Niagara. The intermediate formation, or Clinton, is well represented in many places. There are many places where all three formations are present in one hill. The predominant formation is the Hudson River, which occupies nearly all of the south half of the county, with numerous extensions running into the Niagara of the north half.

No samples of the Hudson River group were taken, the nearest being that of Excello in Butler county.

Of the Clinton and Niagara a number of analyses were made by the previous surveys. The following have been compiled:

Formation.	Clinton.			Niagara.		
Location.	Centerville	Dayton.		Wilson's quarry, Wayne Twp.		
Analyst.	Wormley.	Locke.	Wormley.	Lord.		
Description of Sample.		Made in 1838.		Best stone, first quarry.	Best stone, second quarry.	Rejected stone, second quarry.
Silicious matter	0.85	2.60	3.47	0.80	0.39	4.00
Alumina Oxide of iron	0.40	0.53	0.55	0.83	0.47	1.13
Carbonate of calcium	86.30	92.30	90.03	54.30	54.47	51.97
Carbonate of magnesium	11.34	1.10	5.71	43.69	44.73	42.07
Totals	98.89	96.53	99.76	99.62	100.06	99.17

There is some doubt if one of the samples from Dayton is really Clinton or not. The Dayton stratum of the Lower Niagara has a composition like the best of the Clinton in a nearby section, and it is not unlikely that one or both of the Dayton samples are this typical and famous Dayton stone, and not the comparatively little known Clinton which underlies it.

Mr. Peppel made one careful section in this county, to throw light on the composition and uniformity of the high-calcium Clinton formation. He chose these samples at Centerville in the southeast corner of the county. His remarks follow:

"The Centerville samples were taken from the quarry of the Lewis Talbot Stone Company, of Dayton. Sample 45 represents the stripping, which is made up of clay and limestone mixed with soil. This is five feet six inches in thickness. No. 46 is the famous 'Dayton' stone, a white limestone of great density, carrying iron pyrites. It is only four feet thick at this point. Samples 47 and 48 were two strata of the Clinton, having a thickness of nine feet and eight feet respectively. No. 47 had a stratum of two feet of shale in it. This brings us to the bottom of the quarry. The stone rests on a calcareous shale, which was exposed in a 'sump' hole, blasted out to collect the drainage of the quarry. This shale was sampled in the walls of the sump, to the depth of nine feet."

The analyses follow:

Centerville Samples.

Number of samples.	45	46	47	48	49
Description of samples.	Stripping, 5 ft. 6 in. Limestone, clay and soil.	"Dayton" stone. Next 4 ft. below sample 45.	Next 9 ft. below sample 46. Top of Clinton formation.	Next 8 ft. below sample 47. Clinton.	Next 9 ft. below sample 48. Shale underlying Clinton.
Silica	24.20	2.04	4.02	0.50	29.76
Alumina	11.03	1.05	2.28	0.48	11.39
Oxide of iron	1.45	0.15	0.52	1.00	2.85
Carbonate of calcium	36.85	93.25	88.95	90.95	31.85
Carbonate of magnesium	24.24	2.82	3.59	7.06	21.30
Totals	99.57	99.31	99.36	99.99	97.15

These figures are interesting as showing that locally the Dayton stone is like the Clinton in composition, but not in physical character, and that all of the stones are of the low-magnesia type, while the limestones above, and the shales below, are heavily charged with this substance. It seems in view of these careful sections of the strata, and the earlier analyses, that there are certainly areas of considerable size in this county where portland cement may be made from the lime. The question of economic manufacture still remains, of course, but the resources are there. The stripping in most cases would be very heavy.

MORGAN COUNTY.

Morgan county, lying among the rough, hilly country of southeast Ohio, has not up to this time shown any industries based upon the limestone resources. No reference to them is found in the early reports, though the presence of the stones is amply recorded. Mr. Peppel properly concluded to make several samples in this district. His descriptions of the samples follow:

"Sample No. 148 came from south half of A. D. McCormack's farm, six miles east of McConnellsville. This sample consisted mainly of a buff, earthy stone of conchoidal fracture. There was evidence that this stone would not stand weather well. About two feet of limestone was left out of the sample to provide for what would be lost in mining, on account of the roof. This sample also carried a four-inch bed of shale.

"Sample No. 149 was cut one mile southwest of Unionville, Meigsville township, on the William Tenment place. It consists of six feet six inches of solid blue limestone, with two six-inch stratas of shale.

"Sample No. 150 came from near the head waters of Turkey Run, one and one-half miles west of Stockport. The section there was as follows:

		Feet.	Inches.
	Limestone (roof)	2–4	0
Sample 150	Blue limestone	0	6
	Buff limestone	0	9
	Shale	0	6
	Blue slaty limestone	1	3
	Hard blue limestone	6	0
	Shale	0	6
	Limestone	2	0
	Limestone and shale, interstratified	50	..

"Some of the beds of stone in the strata lying under the sample were as much as four feet in thickness."

The analyses of these samples follow:

Number of samples.	148	149	150
Description of sample.	Well above Meigs Creek coal, 11 ft. Buff limestone.	Well above Meigs Creek coal, 7 ft. 6 in. thick.	Well above Meigs Creek coal, 11 ft. 6 in. limestone.
Silica	8.24	14.66	15.80
Alumina	2.62	3.51	3.40
Oxide of iron	2.50	1.85	0.90
Carbonate of calcium	67.48	67.30	71.88
Carbonate of magnesium	18.24	12.78	8.54
Totals	99.08	100.10	100.52

These analyses disclose a situation very similar to that in Monroe county, viz: no portland cement materials are indicated; excellent prospects for the hydraulic lime industry are shown, if found economically feasible; no prospect for good white lime was found.

These samples all represent the uppermost range of limestones found in the state. The Pittsburg limestones—i. e., those lying between the Pittsburg and Meigs Creek coals—are present on the west of this zone of higher limestones which were sampled. No samples of the lower series were taken, probably because favorable exposures were not seen, though they certainly could be found. The Pittsburg stone may possibly offer more promising material than that of the Meigs Creek horizon.

MUSKINGUM COUNTY.

This county lies wholly within the coal measure area, and its strata present an unusual stratigraphical range. The Maxville limestone occurs on the western edge of the county, in one of its most promising exposures, while on the eastern edge, the strata reach well above the Ames or Crinoidal limestone and probably within a short distance of the Pittsburg coal, though not up to it, thus including the Logan, Maxville, Pottsville, Allegheny, and nearly all of the Conemaugh formations.

The limestones represented are the Maxville, the Lower and Upper Mercer, the Putnam Hill, the Lower and Upper Freeport, the Cambridge, and the Ames, with possibly one or two local veins not recorded in the regular scale.

Of these, but one, the Maxville, offers distinct promise of becoming commercially important. The Mercers are thin, the Putnam Hill, though of good quality for a coal measure limestone, is seldom above four feet and often only one or two. The Freeport limestones are found in basins, not regular, and no exposure of any great thickness is known to the writer. The Cambridge and Ames limestones are not often more than three or four feet thick in this county, but the Cambridge thickens up in Guernsey county, shortly after passing through the Muskingum line.

But two analyses could be found representing the work of the older surveys. Neither are well described and one at least does not represent the characteristic phase of the material from which it was taken. They are as follows:

Description of Sample.	New Concord, lowest limestone, probably Ames, possibly between Ames and Pittsburg coal.	J. H Rob limestone at White Cottage, Maxville Horizon.
Silicious matter	42.29	15.20
Alumina and oxide of iron	8.28	4.40
Carbonate of calcium	49.35	49.80
Carbonate of magnesium	....	30.15
Totals	99.92	99.55

The Maxville limestone is developed in a basin of small extent, but unusual thickness, at Fultonham in the southwestern corner of the county. The Fultonham beds have been quarried for stone for a long time past, but are not now worked. The top of the formation is here on the surface at the valley level, only twelve to fifteen feet above drainage. Massive blocks of it, separated by cleavage cracks, pave the valley of Jonathan's Creek at this point for about a mile. The quarries are necessarily shallow, as the water level is soon reached. Eighteen feet is the maximum depth reached, and this could only be maintained by vigorous pumping.

Mr. A. J. Hoover, of the Fultonham Brick Company, has drilled through the stone in several places, in search of an artesian water supply. He reports the stone as variable, being cut out in spots, and present in points only one hundred feet or so distant. The thickness at the points drilled was about forty-five feet.

There is small hope of finding this basin of thick stone over any extensive area. On going northeast, up the valley of Jonathan's Creek, the stone rises rapidly and in three miles comes up above the bed of the stream, so that the full section can be seen in the railroad cuts along the bank. At this point, the thickness is only fifteen feet, and the chemical and lithological character has wholly changed, the magnesia becoming high, and the stone stratified in beds of markedly different characteristics. Some of these bands are highly conchoidal, buff limestone of apparently high purity. Others are heavy, dense blue bands, others soft, yellow and silicious. No one would recognize the formation as the same one seen at Fultonham, if it were not clearly traceable for the whole distance. Toward the south, the stone goes under cover at once, and no wells or drill holes in that direction have reported any large development of limestone. To the east, down the valley of Jonathan's Creek, the stone can be followed three miles or just below White Cottage. It is dipping faster than the stream falls, so its top layers go under cover shortly. Drill holes three or four miles eastward have been put down without finding large limestone developments corresponding to the Maxville. Northwards the stone may be traced about three miles to the bottom row of sections of Hopewell township. Here it is on drainage level, fifteen feet thick, and somewhat magnesian.

Thus the deposit is actually known to exist in a space of less than six miles long and four miles wide, while the area where the character of the stone is good is three miles long and very narrow. The valuable phase of it occurs at a point where the top of the stratum is rapidly approaching water level. By opening at sufficient distance back from the creek, and using modern methods of quarrying and pumping there is no doubt that a large output of stone could be maintained—larger than any other point known to the writer in the coal measure limestones of Ohio. Unfortunately, only a limited number of such sites can be found in this area, and the investment required to secure them all would be small compared to what large portland cement companies are often willing to spend. This deposit will be further considered in connection with the discussion of the Maxville limestone as a formation, in the succeeding chapter.

The composition of the samples of this stone taken for this report are shown in the following. The samples were taken by the writer, and the analyses were made by Mr. Peppel and Mr. Nauss.

Analyst.	Nauss.	Peppel.	
Number of sample.	——	0-61	0-60
Description of sample.	Fultonham quarries. 12 ft. represented in this section.	White Cottage. 9 ft. of top of formation.	Kent's Run. Hopewell township. J. Stein. 15 ft. in section.
Silica	2.80	3.04	6.96
Alumina	1.16	1.54	2.35
Oxide of iron		0.40	1.85
Carbonate of calcium	92.80	92.92	82.30
Carbonate of magnesium	2.13	1.21	5.72
Totals	98.89	99.11	99.18

The quality of this stone is certainly very good for portland cement manufacture. It has been used for burning, producing a very hot lime of high value. It is not popular with masons who are accustomed to the mild magnesian limes of western Ohio. It has also been used for building stones to a limited extent and for furnace flux, for which it is admirable.

NOBLE COUNTY.

This county is covered with the upper formations of the Carboniferous, chiefly the Conemaugh and Monongahela. The limestone wealth is at a minimum, being confined to those which overlie the Meigs Creek coal. The early reports give nothing on this subject beyond showing the presence of the limestones in sections. The present work is able to add but little. Mr. Peppel found but one point where the exposure justified sampling, viz: on the William Calland farm, one mile east of Somerfield, near the eastern line of the county. The section was as follows, taken from Mr. Peppel's notes:

		Feet.	Inches.
	Buff limestone	4–6	0
	Coal	3	6
	Shale	35–45	0
	Limestone (roof)	2	0
Sample 154 10 ft.thick	Limestone, uneven in bedding	6	6
	Shale	0	6
	Limestone	2	0
	Shale	0	6
	Limestone	0	6
	Shale	..	..

The stone is of conchoidal fracture and does not stand weather well. The analysis is as follows:

		Per cent.
Sample 154	Silica	16.44
	Alumina	5.15
	Oxide of iron	1.65
	Carbonate of calcium	62.30
	Carbonate of magnesium	13.01
	Total	98.55

This agrees with the type of the limestones of the same horizon from Monroe county, just east of this point, and Morgan on the west. It does not promise any wide usefulness under exisiting conditions.

OTTAWA COUNTY.

More lime is burned and probably more limestone quarried in this county than in any other in the state. The formations are three. The Niagara and Waterlime alternate in bands a few miles wide and cross the county from north to south. There are three such bands of Waterlime, and two of Niagara. Finally, there is on the very tip of the Peninsula a little area of Corniferous about four miles wide by four miles long (see map). The quarries are located in three groups, the western at Genoa, the central at Limestone and Rocky Ridge, and the eastern in the Corniferous on the Peninsula.

These quarries were thoroughly studied by Dr. Orton in 1888 and there has been no need to duplicate his work. The following resume of his findings is given:

The quarries at Genoa are located at about the junction of the Springfield beds of the Niagara, and the bottom of the Lower Helderberg. Of the quarries then open, all but one had more or less of the Lower Helderberg on the surface, but all were using the Springfield beds of the Niagara exclusively for the burning of lime. The two beds cannot be distinguished by analysis—both are dolomites of high purity, but by lithological and palæontological evidence, there is said to be no difficulty in distinguishing the two formations.

Niagara (Springfield) Limestones from Genoa, Analyses by Lord.

Description of samp'es.	Newman's quarry. Cap rock.	Newman's quarry. Botton rock.	Wyman & Gregg. Main rock.	Habbeler's quarry. Main rock.	Holt's quarry. Main rock.
Silica	0.04	0.22	0.23	0.28	0.24
Alumina and oxide of iron	0.23	0.51	0.16	0.42	0.44
Carbonate of calcium	55.97	53.04	54.30	55.59	54.61
Carbonate of magnesium	44.27	46.01	45.14	43.67	45.05
Totals	100.51	99.78	99.83	99.96	100.34

These limestones are the basis of a very large and important lime industry, the main output of the quarries going into the kilns.

The next district, around Rocky Ridge, is using the Lower Helderberg or Waterlime formation, and turning out a product not chemically distinguishable from the Genoa product. The analyses are as follows:

Lower Helderberg Limestones from Rocky Ridge District.

Location.	Rocky River.	Limestone Station.
Description of sample.	Kingham's quarry 15 ft. section.	11 ft. section.
Silica	0.87	0.29
Alumina and oxide of iron	0.29	0.25
Carbonate of calcium	54.10	54.12
Carbonate of magnesium	44.27	44.79
Total	99.53	99.45

The product of these quarries is largely lime, as at Genoa.

The Corniferous area is the scene of still larger activities, there being more quarries and more kilns than in any other similar area in the state.

The formation of the end of the Peninsula shows the Lower Helderberg forming the floor rock, about thirty-five feet above water-level at the west end of the Corniferous area, and dipping steadily to the south and east, until its upper surface disappears below the water level at or near

Roessling's dock on Marblehead. In Hartshorn's quarry, which is the westernmost of all, the section shows as follows:

		Feet.	Inches.
Corniferous	Stripping, used for pier stone	2	0
	Cap rock, used for flux, etc.	8	6
	Bottom rock used for lime	11	0
	Interval not exposed, but chiefly lower Helderberg	50	0
	Totals	71	6

Various analyses of the stone from these quarries have been made. The "bottom rock" is so called because by local custom it is the lowest stratum worked in this vicinity. The real bottom of the Corniferous occurs about fifteen feet lower. The lower strata grow progressively more magnesian as they go down, and as it is well known, the Helderberg when reached is a very pure dolomite. The following analyses set forth these relations very well:

Analyses of Corniferous Limestones at Hartshorn, and Vicinity.

Analyst.	Wormley.	Lord.			
Description of sample.	1870. Nature of sample unknown, but probably from low point in quarry.	"Cap rock," used for flux and pier stone. 8 ft. 6 in.	"Bottom rock," used for lime 11 ft. averaged sample.	Next 5 ft. below the bottom rock.	Lowest 5 ft. in the formation, resting on the Waterlime.
Silica	2.70	1.00	2.65	6.48	3.85
Alumina and oxide of iron	3.30	0.37	0.44	0.45	0.65
Carbonate of calcium	65.80	89.20	77.23	64.52	57.98
Carbonate of magnesium	27.95	9.64	18 85	28.83	35.57
Totals	99.75	100.21	99.17	100.28	98.05

Neglecting the Wormley analyses, of which the nature of the sample is not known, this series presents a very pretty reduction in lime and increase in magnesia, as the Corniferous is descended and Waterlime is approached.

Passing eastward, the most of the quarries are found grouped near the end of the Peninsula, at or near Marblehead. The section here has altered by the almost complete submergence of the Waterlime below the level of Lake Erie, and the thickening of Corniferous section to about forty-five feet. The "cap rock" and "bottom rock" of Hartshorn's are still characteristically developed and the lower fifteen feet of stone is silicious and not used.

The cap rock is also used here for crushing, for flux, for pier stone, etc. One firm only use it for lime—The Ohlemacher Lime Company—and they do so because the dip of the rocks have left the cap rock as graphical range comprises from the Logan sandstone to the horizon of the Pittsburg coal in the extreme southeast corner of the county. In the bulk of the county, however, the Freeport coal is the highest formation.

The limestones represented are the Maxville, the two Mercers, the Putnam Hill, the Freeport, the Cambridge, and the Ames. These strata, with the exception of the Maxville, are never thick—two to three feet is the usual development, with four to five feet representing maximum thickening. While they are generally low in magnesia, and high in calcium carbonate, they are often strongly diluted with silica, alumina and iron, becoming dark blue, flinty, or shaly. Frequently their suitability for cement making is enhanced by these very impurities, and they would be used in connection with a pure high-calcium stone as the ideal way of introducing the silica and alumina in its best physical form for combination. An example of stone of this sort is found at Somerset, where the lower Mercer, four feet six inches, is quarried for road material. Its composition from a carefully taken section, procured by the writer and analyzed by Mr. Peppel, is:

	Per cent.
Silica	31.70
Alumina	2.91
Oxide of iron	1.55
Carbonate of calcium	61.75
Carbonate of magnesium	0.83
Total	98.74

Professor Lord (Vol. VI., p. 682) cites an example of the Ames limestone in the Sunday Creek district, which represents the other or pure phase of these thin limestones:

	Per cent.
Silicious matter	2.23
Alumina and oxide of iron	1.26
Carbonate of calcium	94.18
Carbonate of magnesium	1.02
Total	98.69

It cannot justly be said that these thin veins of limestone, no matter how suitable or desirable they are for cement manufacture, are likely to become the basis or accessory of a cement industry under present conditions. The cost of mining them is now prohibitory, except under exceptional conditions and for limited quantities per day. Nevertheless, they are in existence, and may become of great importance under the constant shifting which economic and technical conditions are undergoing.

The Maxville limestone occurs in a number of points in Perry county, and on account of the most favorable appearance of the deposit at Fultonham, just over the Perry county line, the formation was traced with some care.

The town of Maxville, from which the formation is named, lies in Monday Creek township, in the southwest corner of the county. The limestone is found in one of its most characteristic, but not its best, showings on the land of David Hendricks, between Maxville and Winona, and on a number of other farms in that vicinity. The stone has been opened up on a small scale for furnace flux, lime and building stone and presents in its various members a thickness of thirteen or fourteen feet. These figures are probably slightly exceeded at nearby points. The section of the stone is as follows:

	Feet.	Inches.
Shale (roof)	..	..
Sample 53, "Building stone," a hard blue limestone rejected for flux, but used for building purposes	2	0
Sample 52, Shales	0	10
Sample 55, Lime stratum	0	4
Sample 52, Shales	2	0
Sample 51, Buff stratum of limestone	5	0
Sample 54, Gray stratum of limestone	4	6
Shaly limestone	1	0
Sandstones, Logan formation	..	..

These various elements of the section were sampled and analyzed separately. Great care was used in sampling to make the samples thoroughly representative of the strata. Two earlier analyses by Professor Lord are also included.

Analyses of Maxville Limestone from D. Hendrick's Quarry.

Analyst.	Peppel.					Lord.	
Number of sample.	0-53	0-52	0-55	0-51	0-54	——	——
Description of sample.	Building stone stratum, 2 ft.	Shale stratum, 2 ft. 10 in.	Thin limestone in the shale stratum 4 in.	Buff stratum, 5 ft. thick.	Grey or "hard pan" stratum, 4 ft. 6 in.	Grey or "hard pan" stratum.	Buff stratum.
Silica	16.34	43.86	10.16	9.56	6.14	3.60	3.76
Alumina	1.70	17.87	2.34	1.54	1.40	0.60	7.16
Oxide of iron	1.00	2.01	0.50	6.20	0.40		
Carbonate of calcium	80.35	31.15	86.27	54.70	90.96	95.10	57.86
Carbonate of magnesium	0.68	4.31	1.40	27.15	0.90	1.30	30.78
Totals	100.07	99.20	100.67	99.15	99.80	100.60	99.66

Calculating the mean composition of the vein, including everything from the bottom of the gray stratum to the overlying shales above the building stone stratum, the figures become as shown in column 1. Rejecting the buff stone and including everything else, they become as in column 2.

	Column 1.	Column 2.
Silica	16.16	19.50
Alumina	4.71	6.34
Oxide of iron	2.78	1.03
Carbonate of calcium	65.82	71.25
Carbonate of magnesium	10.53	1.88
Totals	100.00	100.00

It is obvious that the first proposition would not do, so far as portland cement manufacture is concerned, on account of the high magnesia. The second proposition, excluding the buff stratum, would produce a mixture of about the right composition for cement, but from a vein only nine feet six inches to ten feet thick, and involves mining or quarrying thirty per cent. of rock not useful for the cement industry, and for which a market would have to be found, or the handling figured as a loss. The difficulties are somewhat further increased by the fact that the stratum is somewhat near to the top of the hills at this place, and the shales which would be the roof would be too much softened by weather to stand heavy blasting. Neither could they be stripped off economically over large areas, and to strip for a narrow zone around the outcrops would not permit a large enough output to be won for a large cement industry. The conclusion is reluctantly reached that at this point this formation offers a possible but poor opportunity for cement manufacture.

Passing northward from Maxville, the formation could not be found in Monday Creek or Jackson townships, though many places were reached at which it is stratigraphically due.

In Section 25, Reading township, on the farm of Thomas Poling, the stone reappears suddenly with a thickness of twenty-five feet. It is divided here into beds, having no resemblance to the Maxville beds. The bottom ten feet six inches are solid, dense, well bedded, blue or light-colored limestones, in ten to fifteen inch courses, and looked promising. The upper twelve or fifteen feet are shaly, of a light buff color, weathering a yellow tint, poorly bedded and unpromising in appearance. A section was cut, from top to bottom, as well as the sloping nature of the outcrop permitted, with the following analyses. The samples weighed about seventy-five pounds each, and were made by the writer and the analyses by Mr. Peppel.

Maxville Limestones in Northwestern Perry County.

Number of sample.	0-56	0-57	0-62
Description of sample.	Thomas Poling farm. Lower 10 ft. of stone.	Thomas Poling farm. Upper 15 ft. of stone.	Between Mt. Perry and Fultonham, in R.R. cut. 23 ft. in section.
Silica	12.94	3.80	9.88
Alumina	2.70	0.94	2.98
Oxide of iron	2.00	2.70	2.02
Carbonate of calcium	72.36	82.35	69.76
Carbonate of magnesium	10.68	8.46	14.71
Totals	100.68	98.25	99.35

The sample 0-62 was taken from a cut of the Zanesville and Western

Railroad between Mt. Perry and Fultonham, in Madison township. The formation here is different from that seen elsewhere. It is composed of more members, thinner strata, and more beds of shale interpolated between the limestones. The gray or white bottom stone of the Maxville section reappears here, giving a most beautiful conchoidal fine-grained stone of apparently unexampled purity, but the stratum is only three and one-half feet thick. Then follows a massive buff stratum, four and one-half feet thick, without partings or bedding. Then two feet of good solid limestone, followed by a buff stratum, a light yellowish, porous rock of extraordinarily small specific gravity, which was calciferous, but only in moderate degree. This stratum was five feet thick. The upper beds of limestone consisted of two hard gray or blue strata, separated by soft calcareous shales and bowlder limestone, full of perfect brachiopod shells, which could be picked out with great ease.

Another deposit of this capricious formation is found at Glenford, on the extreme north edge of the township and county. It has been quarried here for furnace flux, and for road materials during the 1830's, while the Maysville pike or National road was being put through this section. These old workings were long since abandoned and are now so filled up that samples could not be gotten. The stone which appeared here and there was characteristic in its color and appearance. The thicknesses reported vary from six to ten feet.

The results of this investigation are disappointing. The facts may be summarized as follows:

First: The Maxville formation in Perry county is capricious, apparently occupying small basins which do not communicate.

Second: Each deposit found was chemically and lithologically distinct from any other.

Third: The same deposit varied in structure and composition in different parts, to a degree never before observed.

Fourth: The chemical character of the stone varies from very pure high-calcium stones in some strata, to highly magnesian, almost dolomitic, in others. Silicious and shaly strata are common.

Fifth: No deposit in this county was found which seems to offer a valid hope of industrial utility at present. The distance from the Mt. Perry sample, 0–62, to a point where the formation is highly excellent is but small, and a portion of this excellent bed may cross from Muskingum county into Perry county. Such an area probably could not be large, however, as the deposit has become valueless by the time it reaches Mt. Perry.

PREBLE COUNTY.

Preble county contains an interesting lime industry, which has received a careful study by former geologists and by the present investigation. The formations represented are the Hudson River, occupying the southern third, the Niagara the northern third, and the Clinton forming an imbricated and wavering margin between the two. The two upper formations are worked for lime and stone, but so far as is known the Hudson River is not.

The lime industry of the county is fairly large and the limes have been produced for a long time. The early surveys have given the following data on them.

Dr. Wormley in 1869 and 1870 examined samples of the stone from Eaton, where lime was then being burned. His analyses are as follows:

Eaton Limestones.

	Clinton.	Niagara.
Silicious matter	0.35	9.40
Alumina and oxide of iron	0.80	4.40
Carbonate of calcium	85.21	49.75
Carbonate of magnesium	13.56	35.87
Totals	99.92	99.42

Nothing is recorded as to the samples, but the results which they show are not typical of either the Clinton or the Niagara, as we now know them to exist in this region.

Dr. Orton, in 1887 and 1888, studied and sampled this locality with a view to determining what was being done, and what formations were available. He found the industry centered at the New Paris quarries, and Lewisburg. The New Paris quarries were supposed to be on the stratum corresponding to the Springfield stone, but the analysis of this stratum was distinctly different from the usual. Dr. Orton compared this stone in composition to the lower portion of the Corniferous, but still considered it as the Springfield stone.

The Lewisburg quarries he found to be good examples of the Springfield stone, viz: pure high-grade dolomites. His samples, analyzed by Professor Lord, are as follows:

Locality.	New Paris.			**Lewisburg.**		
Description of samples.	Dwyer's quarry upper strata.	Dwyer's quarry lower strata.	Smith's quarry lower strata.	Disher's quarry selected sample.	Disher's quarry averaged sample.	Turner's quarry averaged sample.
Silica	0.61	1.23	2.21	0.60	0.89	1.31
Alumina and iron	0.37	0.38	0.56	0.60	0.45	0.94
Carbonate of calcium	61.33	67.51	67.00	55.20	54.58	52.70
Carbonate of magnesium	37.68	30.84	29.26	43.28	43.93	43.96
Totals	99.99	99.96	99.03	99.68	99.85	98.91

The object of the present investigation being to lay special stress on the cement making capacities of the Ohio limestones, Mr. Peppel in entering this field decided to sample the Hudson River formation at least once, and to study the Clinton formation thoroughly with a view of seeing if the prophecy of Wormley's results could be commercially made good. Mr. Peppel studied three localities with the following results:

"The samples representing the Hudson River group were selected at Camden. They were taken about one mile west of town, from a bluff known as 'The Devil's Backbone.' At the point sampled, there is a vertical cliff about eighty feet high, Paint Creek flowing past its base. The drift at the point sampled was from four to ten feet thick. The rock extends northeast and southwest and west for a considerable distance."

Analyses of Camden Limestones.

Sample number.	54	53	52	51	50	
Description.	The uppermost 10 ft. of the stone.	From 10 ft. to 30 ft. from the surface.	From 30 ft. to 50 ft. from the surface.	From 50 ft. to 62½ ft. from the surface.	From 62½ ft. to 75 ft. from the surface.	Mean.
Silica	9.70	15.28	13.16	14.60	11.62	13.23
Alumina	4.31	6.05	5.15	5.25	4.84	5.24
Oxide of iron	0.85	1.25	0.75	1.55	0.80	1.03
Carbonate of calcium	80.40	70.35	75.90	72.30	76.70	74.50
Carbonate of magnesium	3.09	5.34	3.30	4.37	4.54	4.20
Totals	98.35	98.27	98.26	98.07	98.50	98.20

This material, if its entire cross section were worked, would produce a stone capable of making a hydraulic lime, if burnt at ordinary limekiln temperatures, or capable of making a portland cement if burnt at higher temperatures with some small alterations of its composition by a mixture with a purer limestone and a little fine silica. The composition of this stone on burning would be:

	Per cent.
Silica	20.93
Alumina	8.29
Ferric oxide	1.63
Calcium oxide	66.00
Magnesium oxide	3.16
Total	100.01

This is a little too low in silica and a little too high in lime and alumina for the best results as a cement. This formation shows to an unexpected advantage at this point, and in connection with a purer limestone in small quantities could undoubtedly form the basis of cement industry so far as the technical question is concerned. The economic advantages of the location would still remain to be considered.

"The Eaton samples were taken from the bed and banks of a small stream on the James A. Kautz farm, just below the quarry in which the lower strata of the Niagara are being worked. Sample No. 60 is the bottom of the Clinton, resting on a bed of shale. The point is about two miles south of Eaton.

"The Kautz quarry is a large opening and is working out stone at the rate of six hundred perch per annum. The stripping is clay and gravel, of a depth of four to ten feet. The stratum worked is a blue stone in even beds, of a thickness of fifteen feet. This was not sampled. Its composition was found by Wormley to be that of a dolomite, though impure with silica and alumina. (See first table of analyses given in Preble county.)

"Mr. F. J. Wilson is working this stone at Lewisburg, exclusively for building stone. The quarry is large, sending out about twelve hundred cars annually. No use has been made of the spalls, and in consequence there is an immense pile of stone of small size which could profitably be made into lime or, crushed, or, better still, sorted and put to both uses. The quarry is provided with railroad facilities. Another party is burning lime in the vicinity of Lewisburg."

The analyses of the Eaton samples are as follows:

Analysis of Clinton Formation, near Kautz Quarry, Eaton.

Number of samples.	63	62	61	60	Mean.
Description of samples.	Top down 28 in.	Next 36 in. below sample 63.	Next 42 in. below sample 62.	Next 48 in. below sample 61.	Mean of total section of 13 ft.
Silica	1.02	0.92	0.58	0.74	0.78
Alumina	1.22	1.00	0.47	0.62	0.77
Oxide of iron	0.22	0.10	0.25	0.40	0.29
Carbonate of calcium	95.35	95.20	91.85	94.45	94.10
Carbonate of magnesium	2.21	2.40	6.50	4.07	3.99
Totals	100.02	99.62	99.65	100.28	99.93

These figures are valuable, showing stone of a mean composition which would produce a high grade of portland cement. The detail with which the strata were sampled reassure us as to the worst as well as the best features of the case.

"The New Paris samples were taken from the quarries of Reinheimer Bros.; sample 33 rests on a shale which overlies the Clinton. This bed carried many flint-layers, one for every twelve or eighteen inches. No. 34 was the top ten feet of the quarry and was a handsome even-bedded stone, suited to building purposes. A few hundred yards southwest of the quarry, a hole had been blown out at a lower level, showing about two feet of coarsely crystalline, nearly white stone which was sampled as all that was available of the Clinton. It only represents the extreme top, of course. This sample was very similar in physical character to the Centerville and Piqua samples of the Clinton."

New Paris Samples.

Formation.	Lower Niagara.		Clinton.
Number of sample.	34	33	35
Description or sample.	Building stone, hard, blue, well bedded, top 10 ft.	Flinty courses, next 19 ft. 8 in. below sample 34. Shale below.	2 ft. of the top, taken from below the shale.
Silica	2.50	18.20	1.52
Alumina	1.32	1.89	1.00
Oxide of iron	trace	0.15	0.60
Carbonate of calcium	67.00	54.80	95.10
Carbonate of magnesium	29.32	25.80	1.80
Totals	100.14	100.84	100.02

The composition of the upper course here agrees almost exactly with that given by Dr. Orton in 1888 for the New Paris lime strata. By inference, he says that this is the Springfield stone, but Mr. Peppel's samples of the present workings of these quarries disclose the bottom of the Niagara and the top of the Clinton close below. This would make the blue stone which is used here very doubtfully referable to the Guelph beds. The Clinton, although it seems to lie too low to be easily accessible, apparently has an excellent composition for cement, sugar-refining and similar chemical purposes.

These investigations have disclosed, first, that the Hudson River group has an unusually promising composition at this point. Second, that the Clinton in two localities is present in its best high-calcium phase, and third, that the stone worked elsewhere is the lowest phase of the Niagara, departing from the dolomitic ratio in New Paris and impure at Eaton. In Lewisburg alone is the Springfield stone found in its characteristic composition.

SANDUSKY COUNTY.

Sandusky county has almost the same geological structure as Ottawa county on the north of it, viz: alternating bands of Niagara and

Waterlime formations, passing from north to south, with a patch of Corniferous in the eastern end. There are three bands or patches of the Waterlime, but of less proportionate area than in Ottawa county. The Niagara patches are two in number and of larger area. The Corniferous area cuts off a generous corner of the county, comprising about thirty square miles. Lime industries exist on a large scale in each formation.

The Niagara area is exploited by quarries at Woodville and Gibsonburg in the northwestern corner of the county. The composition is the characteristic dolomite shown by that stratum so generally; the sample was taken by Dr. Orton in 1887 from H. Ranchamp & Co.'s quarries, and the analysis was by Professor Lord.

Woodville Limestone.

	Per cents.
Silica	0.31
Alumina and iron	0.39
Carbonate of calcium	53.50
Carbonate of magnesium	45.79
Total	99.99

The Gibsonburg stone was not analyzed, but it is known to be a pure dolomite also. It is the basis of a large and most progressive lime industry.

The Lower Helderberg area is represented by the lime works of Noble & Company, and Gottron Bros., at Fremont. Dr. Orton diagnosed these beds as being the bottom stratum of the Lower Helderberg, lying just above the Springfield beds of the Niagara. The composition gives no clue, as it is a dolomite of good grade. The following results are available:

Fremont Limestones.

Analyst.	Lord.		Peppel.
Description of sample.	Noble & Co.'s stratum used for lime—1887.	Gottron Bros.' stratum used for lime—1887.	Gottron Bros.' stratum rejected for lime. Top 12 ft. of quarry. Sample 13.
Silica	0.74	0.35	1.06
Alumina Oxide of iron	0.27	0.43	0.42 trace
Carbonate of calcium	54.06	55.65	55.65
Carbonate of magnesium	45.20	42.29	40.66
Totals	100.27	98.72	97.79*

*This analysis is probably a little low on lime or magnesia or both, but it is inserted to show the silica and alumina are not materially different from the lower stone, which is being used.

The Corniferous area is represented by the quarry of the Bellevue Stone Company. This quarry is just inside the Sandusky county line, though Bellevue is in Erie county. This area is supposed to be Corniferous, in fact close to the edge of the Devonian shales which cap the formation, but Mr. Peppel thinks that the quarry inspected and sampled is Lower Helderberg in age, or the extreme bottom of the Corniferous. The following is quoted from his notes:

"The quarry sampled at Bellevue is probably a section of the Waterlime, pushed up above its normal level. There is evidence of much disturbance in this quarry, the stone dipping in different directions, and the entire region is underlain at a depth of eighty or one hundred feet with a large cavern or number of caverns of unknown depth and size.

"A short distance to the southwest, and at about the same elevation, there is a quarry of undoubtedly Corniferous age, which is very different in physical character from the Bellevue stone, and it is probable that the quarry sampled is surrounded by the Corniferous at a short distance on all sides.

"Sample No. 14 is a gray stone with a few courses of flint nodules, about four feet and six inches from the top. This stratum was twenty-three feet nine inches in depth. Sample No. 15 is a brown stone, gray in body, but with many brown streaks in it, so as to give it a brown tint. This stratum is three feet thick. Sample No. 16, twenty-six feet and six inches in depth, consists of a white or light gray stone, usually heavy in bedding, and carrying some courses of soft stone. The quarry is now worked to a depth of thirty-five feet only."

Mr. Peppel's diagnosis arrived at by independent observation is confirmed in a measure by Winchell, Vol. I., p. 604, who found a much disturbed area at this point and pictured a section showing his conception of the structure. It is not, however, certain that the strata sampled belong to the Waterlime, as their composition is not in harmony with that usually found in that formation, while it is much closer to the composition shown by the lower layers of the Columbus formation a few miles distant, on Marblehead. The results reached by Mr. Peppel in his analyses are as follows:

Bellevue Limestone Analyses.

Number of samples.	14	15	16
Description of samples.	Top, down 23 ft. 9 in.	Next: 3 ft. below sample 14.	Next 26 ft. 6 in. below sample 15.
Silica	5.24	8.72	6.32
Alumina	0.96	1.27	2.31
Oxide of iron	trace	0.15	0.05
Carbonate of calcium	56.30	56.10	63.15
Carbonate of magnesium	37.91	34.59	27.97
Totals	100.41	100.83	99.80

SCIOTO COUNTY.

The formations of this county are divided between the sandstones and shales of the Logan, Black Hand, and Cuyahoga formations, representing the Sub-Carboniferous and the lower portions of the Pottsville formation. The older rocks cover the western half of the county, and form the valleys of a large part of the eastern half as well. The Pottsville forms the hill tops in the land just east of the Scioto river, and descending to the east, forms the whole surface formation in the eastern row of townships.

The limestones are scanty in number of formations and in areal development. The Maxville, due at the bottom of the coal measures, is represented locally by a flint fireclay of great purity. This formation occurs in basins or pockets just as the Maxville limestone is suspected of doing. The latter is sparingly represented, if at all, by nuggets or bowlders of limestone, occurring imbedded in clayey strata. Across the river in Kentucky, the limestone is said to be thickening up and becoming persistent.

The Mercer limestones are thin and worthless in most places, but at Howard Furnace, on the eastern edge of the county, the Lower Mercer undergoes a local thickening which perhaps may be found elsewhere if search is made. The stone is here seven feet six inches thick, overlying a thin coal seam. The quality is excellent, as shown by the following analysis.

Lower Mercer Limestone at Howard Furnace.

	Per cents.
Silica	1.02
Alumina	0.62
Oxide of iron	1.08
Carbonate of calcium	94.85
Carbonate of magnesium	0.91
Total	98.48

The extent of the stone of this thickness is not known, but is not thought to be large.

The Ferriferous limestone is found in the hills of the eastern part of the county, forming a part of the Hanging Rock field, which extends from the Ohio river to McArthur. The amount of the stone in Scioto county is relatively small, though considerable in absolute quantity.

It is quarried and mined at Eifort, in Bloom township, by Morgan & Horton, the product being used for flux and cement. The vein at their mines has a thickness varying from seven to ten feet, averaging eight feet. It is a beautiful, pure-looking, conchoidal gray stone, lying directly on the Clarion coal, here of three feet thickness. The section of the strata actually worked in this place is as follows:

	Feet.	Inches.
Hilltop	25	..
Lower Kittanning or No. 5 coal (not open)	..	..
Light colored fireclay	8	..
Fine grained, yellow shale, with some iron ore kidneys scattered through it	25	..
Iron ore	..	6
Ferriferous limestone	8	..
Draw slate	0	3
Clarion or No. 4 coal	3–4	0
Fire clay	4–6	0

The coal is mined first to a depth of six feet, back from the face of the stone. The latter is then drilled and shot down. The roof material consisting of shale, it is necessary to leave two feet of limestone for a roof, which makes the stone available for mining only five to six feet thick. The outcrop of the limestone is stripped by pick and shovel and the full thickness of the stone is thus won (including the coal also) until the stripping reaches a depth of eight to ten feet. Above this depth, it is not profitable to strip.

The stone at this point is free from flint, and is fairly well bedded, so that it can be split in mining better than at some other points where it is worked. The composition is as follows: samples by the writer, analyses by Mr. Peppel.

Number of samples.	0-19	0-20	—
Description of samples.	Cross section of vein as mined 5 ft. thick	Drillings from power drill holes.	Average of 9 analyses from Alma Cement Works.
Silica	1.76	0.53	....
Alumina Oxide of iron	2.03	1.55	....
Carbonate of calcium	94.50	95.62	93.50
Carbonate of magnesium	0.80	0.81	....
Totals	99.09	98.51	....

The quality of the Ferriferous limestone in this western edge of its field is thus seen to be most excellent for cement manufacture or other chemical purposes. A somewhat fuller discussion of the economic conditions affecting its winning will be given in chapter four.

There are no limestone beds higher stratigraphically than the Ferriferous in Scioto county.

SENECA COUNTY.

Seneca county resembles Ottawa and Sandusky counties in consisting of strips of Niagara, Lower Helderberg, and Corniferous limestone, but the conditions are simpler, in that there is but one patch or area of each formation. The Niagara covers the entire western end of the county, bounded on the east by a diagonal line, from Adrian to Green Springs. The Lower Helderberg occupies a narrow wedge-shaped strip, parallel to the line just indicated and about four to five miles wide on the north and eight to nine miles wide on the south. The Corniferous occupies the eastern end of the county, except for a small area of shales covering the southeastern corner. Each formation covers about one-third of the surface of the county.

Quarries have been opened in each formation and in times past a considerable industry has been maintained from lime and stone. The industry still prevails to some extent. At Fostoria, the quarries are in the Niagara, and are favorably situated for cheap working. The stone was sampled by Dr. Orton in 1887, and analyzed by Professor N. W. Lord. Another analysis was secured by Mr. Peppel, without learning the analyst's name. No new samples were taken, as the formation is thoroughly typical.

Fostoria Limestones.

Analyst.	Lord.	——
Silica	0.42	0.37
Alumina and oxide of iron	0.28	0.34
Carbonate of calcium	56.41	54.46
Carbonate of magnesium	41.98	44.35
Totals	99.09	99.52

At Tiffin, lime has been burned for local use for a long time. The quarries are on the point of contact of the Niagara and Lower Helderberg, so that both formations are used. Both are characteristic dolomites.

The Corniferous is worked at Bloomville, on a rather extensive scale, the output being chiefly crushed stone. Mr. Peppel's remarks on the Bloomville quarries follow:

"At Bloomville, the same cap rock mentioned elsewhere shows up, overlying the dark-blue Delaware formation. Samples were taken in the E. H. France Company's quarry, about one and one-half miles southeast of the depot. The top stratum, three feet six inches thick, was a gray stone, with several courses of flint nodules. This constitutes sample No. 10. The next sixteen feet are a blue limestone, full of flint nodules, and unfit for any chemical purpose. This constitutes sample No. 11.

The next six feet are No. 12, consisting of a hard blue stone, in even beds, free from flint. The quarry has been worked to a depth of ten or fifteen feet below sample 12. The main product of the quarry is crushed stone for railroad ballast. Some building stones of large dimensions are taken out in the strata represented by sample No. 12. They can furnish stones twenty-six inches thick, and of almost any desired length. The stripping is heavy, averaging thirteen feet of gravel. Every few years the railroad runs in a temporary track and with a steam shovel the gravel is loaded onto cars; this gravel the railroad uses for ballasting its roadbed."

The analyses follow:

Number of samples.	10	11	12
Description of samples.	Top. down 3 ft. 6 in. gray stone.	Next 16 ft. below sample 10. Hard, blue, flinty stone.	Next 6 ft. below sample 11. Hard, blue, well bedded stone, no flint.
Silica	2.96	22.76	4.38
Alumina	0.41	1.44	1.90
Oxide of iron	0.15	0.10	trace
Carbonate of calcium	89.55	62.30	74.05
Carbonate of magnesium	7.46	13.18	20.30
Totals	100.53	99.78	100.63

There is some room for doubt as to the identity of the "cap stone" mentioned above, and the analyses are not sufficient to settle the question, as the upper portions of both the Delaware and Columbus formations have shown an almost identical composition at different points, viz: 85 to 90 per cent. carbonate of calcium to 7 to 12 per cent. carbonate of magnesium. The lithological character of the stone, its color, and flint courses all suggest the Delaware formation. In any case, its chemical character and utility are as represented. There are no other quarries operating in this vicinity.

SHELBY COUNTY.

Shelby county lies wholly in the area of the Niagara formation. Its limestone is strictly typical of the formation, viz: a nearly pure dolomite. Of this stone, it has extensive supplies accessible where the ravines have cut through the mantle of drift clays. It has been worked at a number of points, notably at Sidney, which formerly was a heavy shipper of lime to the Cincinnati market. It is now wholly abandoned.

Mr. Peppel found no quarry industries of important proportions in the county. The composition of the Sidney lime, as found by Wormley in 1870, is as follows, the sample being taken from Drugan's quarries:

Sidney Limestone.

	Per cent.	Per cent.
Silicious matter	trace	0.20
Alumina and oxide of iron	1.60	0.50
Carbonate of calcium	55.00	54.40
Carbonate of magnesium	42.92	44.58
Totals	99.52	99.68

It is evident that economic conditions will be the controlling feature here in the future development of the white lime industry. Certainly the material itself is abundant and of high purity.

STARK COUNTY.

Though lying wholly in the coal measures, Stark county does not present a very great stratigraphical range. The horizon of number 1' coal, at Massillon, is not characterized by any development of the Maxville limestone stratum. The Mercer limestones are persistent and easily recognized, but thin. The Putnam Hill limestone is also generally distributed over the eastern two-thirds of the county. It is quarried south of Canton for road material and to supply one small lime kiln, and there presents a thickness of four to five feet, of good gray crystalline stone. None of the higher limestones are found, not even the Lower Freeport.

The Putnam Hill formation exhibits at Middlebranch, Plain township, a local thickening to eight feet, which has attracted a portland cement industry. The Diamond Portland Cement Company begun making cement there with two double Dietsch kilns, but have recently remodeled and put in rotary kilns. They are reported to be making an excellent product from this stone. Its composition, from an average sample taken by Mr. Peppel, shows as follows:

Putnam Hill Limestone, Middlebranch.

		Per cent.
Sample182	Silica	4.12
	Alumina	1.86
	Oxide of iron	1.20
	Carbonate of calcium	91.16
	Carbonate of magnesium	1.63
	Total	99.97

It is not improbable that other points equally favorable could be located in this vicinity. The stone has been won so far by stripping around the crop line; as it lies not far from the top of rounded gently-sloping hills, the benches from crop to point where the stripping becomes too heavy is wide enough to make the stone fairly cheap by this method.

It would be difficult to support a large industry by this plan, and mining would be preferable for regularity of output in all kinds of weather. Conditions, however, in the vicinity of Middlebranch suggest that mining would be impossible.

TUSCARAWAS COUNTY.

Tuscarawas county lies well within the borders of the coal measures, and its strata range from a little below the Lower Mercer limestone in the northwestern corner, to well above the Freeport in the southeast. A number of thin limestones occur in the otherwise barren strata above the Freeport coals, in the townships of Washington, Perry and Rush, but none of them have enough continuity or thickness to have value.

In no place in the county do any of the various coal measure limestones assume any importance. They are present with great regularity, and characteristic color and appearance, but thin and economically worthless. The only point where a thickness is reached which seemed to justify sampling was at New Philadelphia, where the shale under the Lower Kittanning coal assumes locally a calcareous and silicious phase. This was sampled in two portions, top and bottom, the total cut being about twelve feet. The results by Mr. Peppel are as follows:

Impure Limestone from New Philadelphia.

	Top.	Bottom
Silica	51.40	53.84
Alumina	3.66	6.70
Oxide of iron	2.00	2.40
Carbonate of calcium	42.20	35.10
Carbonate of magnesium	0.53	0.53
Totals	99.79	98.57

The proportion of lime in this rock is too low, in itself, to be of value for any purpose. It might be a very convenient and technically admirable way of adding silica to a high-calcium stone, for portland cement manufacture. The use of clay for this purpose is often troublesome, but the use of a calcareous rock, high in silica in the amorphous condition, and practically free from magnesia and low in alumina, would be chemically very desirable. Whether it would pay to transport it from its point of occurrence to a distance for this purpose is an economic question which cannot be settled here.

VAN WERT COUNTY.

The strata of this level prairie county are divided between the Niagara, occupying a triangular quarter in the southwest, and the remaining three-quarters, consisting of Lower Helderberg. The lime industries are of no great importance. But one place was found where large quarries were operating, i. e., at Middle Point, where the Lower Helderberg is open to a depth of twenty-two feet. Mr. Peppel describes this stone as being fairly hard, rather thin in bedding, with numerous blue and brown streaks in it. The stripping is six feet in thickness. One of the largest operators there is The E. H. France Company, from whose quarry one sample from top to bottom was taken as No. 29.

The analysis is as follows:

	Per cent.
Silica	1.12
Alumina	0.52
Oxide of iron	trace
Carbonate of calcium	54.55
Carbonate of magnesium	43.56
Total	99.75

Undoubtedly stone of this quality can be had at many favorable exposures over the country.

WARREN COUNTY.

The strata of Warren county are substantially confined to the Hudson River group. One or two small islands, in which the Niagara forms the surface, are found in the north and northeast, but even here the Niagara is merely the cap rock of the hill, and the valleys and slopes are all in Hudson River rocks. These strata were not sampled carefully in the earlier work, because it was thought their minerals were useless for industrial purpose. Only one analysis, by Wormley, in 1869, could be found.

The Hudson River formation was sampled by Mr. Peppel with some care, at one point in this county. Of the samples, he says:

"Samples were taken from a ravine, north of the depot and west of the Pennsylvania railroad at South Lebanon. The bottom of sample No. 102 was about thirty feet above the level of the river. Considerable drift covers the stone at this point."

Number of sample.	103	102	
Description.	From top layer down 50 ft.	Next 40 ft. below sample 103.	Mean.
Silica	23.30	29.00	25.83
Alumina	9.11	9.57	9.31
Oxide of iron	2.05	3.15	2.54
Carbonate of calcium	60.08	52.63	56.77
Carbonate of magnesium	3.28	3.52	3.39
Totals	97.82	97.87	97.84

Here we have a stone in which so much clay matter has been included that no use could be made of the mixture. What could be done in the way of excluding the shale, and winning clean limestone, was not recorded in making the sample.

There is great probability that strata could be obtained, with comparatively little handling of waste material, which would run ten or fifteen per cent. higher in lime than these cross section samples have done, and that the magnesia would not be greatly affected by this selection process. The use of the material for portland cement would require either the use of a selected material, or the importation of some high-calcium stone from the nearest Clinton outcrops, for mixture.

The stone offers no prospect of use in any other connection.

WASHINGTON COUNTY.

This district lies in one of the most elevated portions of the state, stratigraphically considered. On its western edge, the Meigs Creek coal and its limestones are found, while the valleys go down into the complex limestone groups which lie between the Pittsburg and Meigs Creek coals. On the north, the hills contain the Meigs Creek group chiefly, while in the southern edge of the county, along the river, the lime strata run under drainage and are not seen.

Little or no attention has been paid to these limestones in this area heretofore, the single analysis from the district having been made by Professor Wormley, in 1869.* The sample was selected in Whipples run, a branch of Duck creek, in Salem township. The thickness was represented as being six feet three inches, but nothing was said as to whether the full section was taken in the sample. In fact, it is not likely that it was. The analysis is as follows:

	Per cent.
Silicious matter	19.10
Alumina and oxide of iron	8.56
Carbonate of calcium	47.70
Carbonate of magnesium	19.40
Combined water	2.50
Total	97.26

Dr. Andrews' report suggests the use of this material for hydraulic cement or lime, which still remains the only purpose to which it could be applied.

Mr. Peppel investigated the lime resources with considerable care, selecting samples in six localities well distributed over the county, geographically. Beginning on the west, he reports as follows:

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*Rept. Prog. 1870, p. 450.

"Sample 138 was taken from the farm of E. F. Glazier, of Marietta, on the northwest quarter of section 1, Wesley township. The section here shown embraced:

		Feet.	Inches.
	Sandstone	..	..
	Shale	8–9	0
Sample 138 9 ft. 6 in.	Limestone	1	0
	Shale	0	6
	Limestone	0	6
	Shale	0	9
	Limestone	1	0
	Shale	0	6
	Limestone	1	0
	Shale	0	3
	Limestone	4	0
	Red shale	..	..

"This section is thought to lie about twenty-five or thirty feet below the Meigs Creek coal, but as no coal was seen, its identification is by no means sure.

"Sample 139 came from the farm of Lillian Reardon, located on Brins run, fraction 5, near section 11, Wesley township. The strata shown were:

		Feet.	Inches.
	Sandstone	..	..
	Shale, light	..	..
Sample 139 15 ft. 6 in.	Limestone	4	0
	Shale	2	0
	Limestone	0	6
	Shale, with nodular limestone	2	0
	Lime	2	0
	Shale, with nodular limestone	2	0
	Limestone	2	0
	Shale, with nodular limestone	1	0
	Shale	..	..

"Nothing was found to positively identify this stone, but it is probably a little above sample 138, stratigraphically, and under the Meigs Creek coal.

"Sample 140 was taken on James Wagner's farm, near the point where the Chester Hill road crosses Coal run, in the northern end of Wesley township. There appeared to be twenty to thirty feet of limestone and shale interstratified here, but it could not all be reached in a satisfactory manner for sampling.

"The portion cut was as follows:

		Feet.	Inches.
	Shale, to sandstone above	..	..
Sample 140 11 feet	Limestone	1	6
	Shale and nodular limestone	2	0
	Limestone, hard and solid	7	6
	Shale, nodular limestone and limestone interstratified	..	..

"This sample also is believed to lie shortly below the horizon of the Meigs Creek coal."

The analyses of these three samples, which were taken in a line a few miles apart, and which are likely to be of the same horizons, are as follows:

Wesley Township Limestones, Below the Meigs Creek Coal.

Number of samples.	138	139	140
Description.	9 ft. 6 in. thick south end of township.	15 ft. 6 in. thick middle of township.	11 ft. thick north end of township.
Silica	18.46	25.28	14.32
Alumina	6.33	8.47	4.82
Oxide of iron	2.47	1.87	1.66
Carbonate of calcium	63.10	58.17	73.67
Carbonate of magnesium	8.82	3.70	5.20
Totals	99.18	97.49	99.67

None of the foregoing offer any particular hope of ultimate utility for portland cement, but Nos. 138 and 140 could undoubtedly be employed in the manufacture of hydraulic limes or roman cements, if markets could be found for the products. The composition for these purposes seems well suited.

"Sample 147 was obtained on the north branch of the west fork of Wolf creek, one mile west of Waterford. Twenty to thirty acres would be available here, with a stripping of less than ten feet. Two or three feet of the top of this stone is not included in this sample. Ten feet and six inches of solid limestone was sampled, and six inches of calcareous shale at the base of the limestone. This brought the cutting to low water level in the creek."

Another sample was secured in Adams township, from the Nicholas Basil place, on the west branch of Cats run, three miles northwest of Lowell. The strata here present the following cross-section:

		Feet.	Inches.
	Coal	..	..
	Sandstone	40–50	0
	Limestone	5	0
	Shale	6	0
Sample 144	Limestone (buff)	2	6
Sample 145	Shale	1–6	0
	Limestone	6	6
	Coal, Meigs Creek	3	0

"Another sample was cut at a point two and one-half miles north of the south line of Lawrence township, on the J. D. Lehmer farm, one-half mile south of Cow Run P. O. The limestone is just dipping under drainage level at this point, the sample being taken in the bed of Cow Run. It consisted of seven feet of dark blue solid limestone; its stratigraphical location is uncertain."

The analyses of these samples follow:

Number of sample.	147	145	146	144
Description.	Waterford, 11 ft. thick close to drainage level.	Lowell, 7 ft. thick just above Meigs Creek (?) coal.	Lowell, 2 ft. 6 in. just above sample 145.	Cow Run. 7 ft. thick. At drainage level.
Silica	11.60	14.84	16.80	12.60
Alumina	3.17	3.93	4.76	4.89
Oxide of iron	1.25	1.65	3.00	2.44
Carbonate of calcium	73.60	65.09	44.08	67.35
Carbonate of magnesium	10.00	14.54	28.44	10.41
Totals	99.62	100.05	97.08	97.69

These samples, selected at well chosen intervals, geographically and stratigraphically, and including the great belt of limestones both above and below the Meigs Creek coal, settle with considerable authority the question of the character of these stones. There is no strong hope of finding any portland cement material in Washington county, and the material present seems likely to find limited use in any chemical field. In construction work these stones, by virtue of some special color or hardness or fine bedding, may become valuable locally, but otherwise they are not likely to be used.

WOOD COUNTY.

The area of Wood county covered by the Corniferous formation is about one and one-half townships on the western edge, viz: Weston and part of Milton. The rest of the county is divided between the Niagara and Waterlime formations, with the latter predominating.

The lime industry is well developed here. In 1888, the burning was done with natural gas. Now the gas has become too expensive, and coal is the principal dependence. The upper portion of the Niagara is used almost exclusively. The stone presents a very superior phase here as shown by the following analyses, taken from the report of Dr. Orton (1888):

Niagara Limestone from Wood County.

Locality.	Bowling Green.	Rising Sun.	Luckey Station.
Description of sample.	Thurstin quarry.	Wyman, North & Company's quarry.	Wyman & Gregg quarry.
Silica	1.53	0.57	0.43
Alumina and oxide of iron	0.40	0 63	0.35
Carbonate of calcium	53.98	53.21	54.20
Carbonate of magnesium	43.25	45 37	44.44
Totals	99.16	99.78	99.42

The lime produced from these stones is marketed on a large scale. The resources of the county in this material are inexhaustible.

The Corniferous formation is not worked to any extent. Search for samples by Mr. Peppel was rewarded at Weston. He says:

"The samples marked Weston came from about two miles west of that village. No. 25 was taken from the J. H. Kline farm, where about six feet of stripping is encountered. The stone is thin-bedded and shelly. No. 34 came from the Pew quarry, which probably joins on closely below No. 25. This stone is blue and even bedded, resembling the Delaware stone. Several flint layers come in about ten feet below the top of No. 25." The analyses follow:

Corniferous Limestones from Weston.

Number of sample.	25	24
Description of sample.	4 ft. top stone, Kline farm. Shelly cap rock.	13 ft. Pew quarry. Blue layer stone.
Silica	3.16	3.76
Alumina	0.68	0.62
Oxide of iron	trace	trace
Carbonate of calcium	83.25	56.15
Carbonate of magnesium	12.98	40.22
Total	100.07	100.75

The similarity of these stones, in composition and appearance to the stone of the Delaware formation at Delaware is suggested, but no absolute decision was reached as to the identity of the strata. The industry built up upon the Corniferous lime in this vicinity is not large, so far.

COUNTIES HAVING UNUSED LIMESTONE ASSETS.

The counties in which the lime resources have been described at more or less length are those in which the present survey or former surveys have found lime industries exploited. These number fifty-five. Beside these, there are eight others in which lime formations occur of sufficient size and importance and of supposedly sufficient quality, to enable them to enter the market as producers on substantially equal terms with those described. These counties are as follows:

Auglaize County.—The Niagara and Lower Helderberg limestones are the surface formations in this county, in about equal proportions. The topography is flat, and the district is on a watershed, so that very few natural ravines or cuttings are found through the mantle of drift which covers everything. Undoubtedly, the limestones are closer to the surface at some points than at others, and undoubtedly they are exposed in some points to quarrying operations. But the general situation is one which does not offer any natural inducements to enter the stone or lime industry.

Henry County.—Henry county is traversed by a broad band of Corniferous limestone from southwest to northeast. This band is about six or eight miles wide and covers more than one-third of the county. The southeast corner of the county is covered with the Lower Helderberg formation and the northwest with the Ohio shale. The character of the Corniferous can be judged from the analyses of the Defiance stone on the west border, and the Weston stone on the east border.

The Corniferous is at present under a disadvantage in the markets against the white dolomite limes of Wood and Ottawa counties, but its higher per cent. of lime gives it a great chemical activity, and in the opinion of the writer, when limes of this class are given the most modern treatment their superior value will become generally recognized. The reputation already reached by the limes of Sandusky, Marblehead and Kelley's Island are a case in point.

The character of the Lower Helderberg is not known in this area, but there is little risk in predicting it to be a dolomite of high purity.

Madison County.—The Lower Helderberg or Waterlime covers almost the entire area of this county. It is not worked anywhere to any important degree. Though its topography is generally flat, there are numerous places where its drift is cut through and the stone exposed to attack. The reason for its tardy development can probably be found in the large lime and stone producing centers on either side of it, at Springfield and Columbus. The starting of a new industry under this competition would be difficult, but the mineral resources are there, and can be utilized when the time comes. Nothing but pure dolomitic lime need be expected.

Paulding County.— Paulding county is divided almost exactly into two equal parts by an east and west line, the northern part being covered with Corniferous and the southern with Lower Helderberg. The Corniferous has been analyzed near Defiance, some three or four miles from the Paulding county line, which gives a key as to what to expect of the formation in this neighborhood. No analyses of the Waterlime are available. Numerous exposures of both formations exist, but no industries of importance as yet.

Pickaway County.—An area of about one hundred square miles of Corniferous limestone lies in the northwestern corner of this county. The balance is in the Ohio shale formation. The limestone has been analyzed at Morgan's station, only a couple of miles from the Pickaway county line, and there is every reason to expect the formation to retain the character it shows at Columbus and Morgan's, down to its southern terminus. It is exposed at points along the course of the Big Darby.

Putnam County.—The county, save for a few square miles in the northwest corner, lies wholly in the Lower Helderberg formation. Its topography is flat, no deep river channels are cut, and the lime is not often exposed to easy attack. No industries of importance based on it are known to exist.

Union County.—The Lower Helderberg formation covers all but a small area of thirty square miles in the southeast corner, which is covered with the Corniferous. There are no analyses available, but the character of both formations at nearby points in Franklin, Delaware, Marion, and Logan counties warrants the inference that the Corniferous will furnish a stone ranging from ninety to seventy per cent. of calcium carbonate, according to the stratum chosen, while the Helderberg will yield a high grade dolomite. The topography of the county is smooth.

Wyandot County.—This county is rich in lime resources, having its area divided substantially into one-quarter of Niagara limestone on the west, one-half in the center, of Lower Helderberg, and one-quarter on the east, of Corniferous limestone. Only the Niagara has been worked to any extent. A quarry at Carey produced in 1888 one of the whitest and purest limes on the market. No other openings are known. The resources are undoubtedly of the best.

COUNTIES HAVING POOR LIMESTONE RESOURCES.

In this group may be placed five counties, all in the coal measure area of the state, viz: Carroll, Coshocton, Harrison, Meigs and Vinton, These counties all have the coal measure limestones present—some in occasionally fair developments, but none which favor the establishment of a lime industry. They could produce their own lime, if other supplies were shut off, but while good lime can be cheaply bought they will not.

Carroll County.—Carroll county possesses the limestones from the

Ferriferous up to the Ames horizon, or possibly the stone below the Pittsburg Coal. No large exposures are known.

Coshocton County.--This county possesses the formations from the Lower Mercer to the Freeport limestones. There are many places where the Putnam Hill formation is four feet or possibly five feet thick, and of good gray crystalline stone. The Mercers are thin and generally flinty. The Freeport stone is nowhere thick, so far as is known.

Harrison County.—This county lies on the edge of the Pittsburg and Meigs Creek limestone formations, and undoubtedly shares in the development of those beds which has been described in Jefferson and Belmont counties. As nothing of great economic promise was discovered in those districts, it seems unlikely here also. No tests were made of the formations lower than the Pittsburg; there are a few of calcareous nature. The Lower Freeport is above drainage in the northwest corner. So far as known, it is not of workable thickness.

Meigs County.—Although it possesses the Pittsburg coal in abundance, it is not known to have any favorable showing of the limestones which are found so abundantly above it, in Athens county. The strata range between the Kittanning coals to above the Pittsburg coal.

Vinton County.—The northern part of this county contains only the Mercer horizons, but of poor thickness and quality. The southern portion contains the Ferriferous limestones of high purity, but unfortunately in small, irregular areas and of inferior thickness. Four or five feet is common here, while six or eight or ten are found in Jackson county, just south. This stone may be capable of furnishing the material for a successful portland cement industry in Clinton, Elk, Madison, and Knox townships. It certainly could in Vinton and Wilkesville townships, where the stone is eight feet thick. In fact, a large plant has been laid out at Oreton in Vinton township. The stone here has a composition as good as the formation furnishes anywhere.

COUNTIES DEVOID OR PRACTICALLY DEVOID OF LIMESTONE RESOURCES.

In this list are included those counties in which the limestone formations do not come to the surface. By coming to the surface is meant forming the nearest solid rock in situ, beneath the drift coating which covers two-thirds of the state. Where resort would have to be made to mining to to obtain the limestone, it is considered that there is no resource in limestone available. Likewise, in coal measure counties, where limestone horizons are due, but not known to be present, that county is included in this list. Some outcrops not known to the writer certainly exist in these counties, but for all practical purposes they are not to be considered as possible competitors in the limestone industries. In this list the following counties are placed:

Ashland,
Ashtabula,
Cuyahoga,
Fairfield,
Fulton,
Geauga,
Huron,
Knox,
Lake,
Lorain,
Medina,
Morrow,
Pike,
Portage.
Richland,
Ross,
Summit,
Trumbull,
Wayne,
Williams.

CHAPTER IV.

THE COMPOSITION, PHYSICAL CHARACTER AND USES OF THE LIMESTONES OF OHIO, CONSIDERED BY GEOLOGICAL FORMATIONS.

BY EDWARD ORTON, JR., AND SAMUEL VERNON PEPPEL.

The formations to be considered comprise the Hudson River group, the Clinton, the Niagara group, the Lower Helderberg or Waterlime, the Upper Helderberg or Corniferous, the Maxville, the Lower and Upper Freeport, the Cambridge, the Ames or Crinoidal, the Pittsburg group and the Meigs Creek group.

It should be again stated at this point, that the principal object sought in the preparation of this bulletin was to marshal all available information on Ohio's limestone resources with reference to the portland cement industry. The impossibility of doing this without also studying the lime resources in general, and with references to other lines of use is at once apparent. The excellent report of Dr. Orton, in 1888, presented a great volume of information about the limestones of Ohio and their utilization, and this has heen used largely in the present report, with such additions as nearly twenty years of growth and change have rendered necessary. It has not, however, been deemed proper to reproduce Dr. Orton's article in full, and attention has been chiefly devoted to considering at most length the phases to which he paid least attention.

Reference to the map, Chapter I, page 30, will be constantly necessary in this chapter, as well as in the preceding.

THE LOWER SILURIAN OR HUDSON RIVER GROUP.

The Lower Silurian limestones form a distinct type by themselves stratigraphically, lithologically, and chemically. No effort has been made here to distinguish between the various stratigraphical elements now recognized in this group, except in the case of the Trenton limestone which is most clearly differentiated, at least in the popular mind. In the case of the Utica shale, the Lorraine, the Richmond, the Saluda, and the Medina formations, no separation of samples was attempted. Samples were taken at various points, wherever thick limestone beds, advantageously exposed by ravines or quarries, were found, and where commercial winning of the stone would be likely to prove feasible. They probably represent calcareous bands from all, or almost all, of the various subdivisions above listed.

THE TRENTON.

As already stated, the Trenton limestone appears above the surface in but one place in Ohio, viz: at Point Pleasant, Clermont county, where it presents a few feet of not valuable stone for a short distance above low water. The composition, as determined years ago by Dr. Wormley, is given in Chapter III, under Clermont county.

Besides this analysis, dozens of analyses have been made of this formation, in Ohio, Indiana, and elsewhere, in connection with borings for natural gas and oil, but these have purposely been excluded from this report. The object here has been to discuss only those formations that are likely to have economic value under such industrial conditions as now exist, or as we may reasonably expect them to exist in the near future.

It is not reasonable to expect that limestones buried at depths of many feet, often many hundreds of feet under ground, will be exploited for lime, cement, chemical uses, or building material, when in whole counties near by, other limestones are the superficial formation and easily accessible to quarrying, drift mining or other cheap methods of excavation. Consequently, only the superficial deposits are considered, and as the Trenton is nowhere a superficial deposit, its character has not been here considered. The same holds true of the Clinton, and other formations at various points, where disclosed by the drill.

FORMATIONS ABOVE THE TRENTON

These formations are composed of comparatively thin beds of limestones, interstratified with calcareous shales. The shale occasionally develops into comparatively thick strata of fifty or more feet, free from hard limestone streaks, though it retains its calcareous character to an extent which everywhere disqualifies it for clay working purposes. The limestones on the other hand never thicken up into a large body free from shaly inclusions. The shale partings vary from an inch or so up to many feet, while the limestone courses vary from a few inches up to fourteen inches. The shales are always silicious, aside from their calcareous character, and are fine grained for the most part, which makes them of possible value as an element in portland cement manufacture. There seems some evidence, however, that the shales are often higher in magnesium carbonate than the limestones which accompany them.

Areal Development.—The formation is the exclusive or practically exclusive superficial rock in situ in Hamilton, Clermont, Brown, Butler and Warren counties, and covers large areas of Preble, Montgomery, Greene, Clinton and Highland counties, and small unimportant areas in Miami, Clark, and Adams counties. (Consult map).

Physical Character.—The limestone of this formation consists of a hard, coarsely-crystalline rock, with color ranging from a rich purplish black to a gray. Its fracture is rough and uneven, yet it can be worked as a building stone, and on account of its rich color and crystalline surface some very pretty effects are produced. It weathers to a somewhat lighter color.

The nature of the deposit is different from anything in the state. It is always interstratified with a fine grained shale, layer for layer. Two beds of limestone seldom, if ever, come together, but are always divided by a strip of shale varying anywhere from an inch to four feet in thickness. The courses of limestone vary in thickness from one inch to twelve or fourteen inches, seldom reaching a greater thickness, and mostly running from six to nine inches for the workable stone.

The layers are extremely tight bedded—i. e., there are almost no horizontal crevices such as appear in most other limestones. This lack of crevices or joints makes quarrying much more difficult.

It is an expensive stone to quarry for three reasons: *First:* It is almost impossible to quarry by wedging into desired dimensions, since there are no fissures to force apart and thus form a working face. *Second:* On account of the intercalated shale, the explosives used are not nearly so effective as they would be on solid rock. The product is also very irregular and ragged, and in consequence of this, there is great waste in dressing the stones into shape for construction work. *Third:* A large amount of shale must be handled in winning the stone. These reasons make it clear that it will never develop much importance as a building stone.

In its favor may be said the following: *First:* It occurs in comparatively even beds, making it possible to easily select range-stone, or stone of the same thickness. *Second:* It could be quarried in very large slabs if sufficient labor and care were spent in getting it out. *Third:* It often occurs in such a way that faces are exposed frequently to a great height, from twenty to one hundred and twenty feet, usually with running water below, so that the waste shale and stripping will wash away at least once a year if it is merely tumbled down. The stripping is usually light.

Chemical Character.—The stone by itself is among the purest varieties of carbonate of calcium found in the state. It is, therefore, low in carbonate of magnesium, more so than any other stone in the western series. This is shown well in analyses 54, 83, 84 and 85, which are probably typical of the limestone independent of the shale which is always interstratified with it. The color of the stone is due to iron, manganese, and organic matter. The table of analyses follows:

TABLE I.—Analyses of the Limestones

Serial number of samples.	Location of quarry.	Thickness and relative position of stratum represented by this sample.
83	Adams Co., Manchester	From top layer down 21 feet...............
84	" " "	Next 12 feet below sample 83..............
85	" " "	From water level, up 20 feet...............
86	Brown Co., Georgetown	From top layer, down 16 feet, 6 inches......
87	" " "	Next 23 feet below sample 86..............
88	" " "	Next 50 feet below sample 87..............
89	" " "	Next 26 feet below sample 88..............
90	" " "	Next 30 feet below sample 89..............
66	Butler Co., Excello	From top layer, down 10 feet 6 inches.......
65	" " "	Next 10 feet 6 inches below sample 66 ......
58	" " Hamilton	From top layer, down 11 feet ....
59	" " "	Next 15 feet below sample 58..............
57	" " "	Next 15 feet below sample 59..............
56	" " "	Next 8 feet 6 inches below sample 57 ....
55	" " "	Next 1 feet below sample 56...............
91	Clermont Co., Bethel	From top layer, down 18 feet ....
78	" " New Richmond ..	From top layer, down 20 feet ....
79	" " " " ..	Next 5 feet below sample 78..............
76	Hamilton Co., Cincinnati	From top layer, down 8 feet ....
72	" " "	Next 18 feet below sample 76..............
73	" " "	Next 17 feet below sample 72..............
74	" " "	Next sample below sample 73...............
75	" " "	Next 13 feet below sample 74..............
77	" " "	From 85 to 107 feet from top of quarry .....
92	" " "	Next 22 feet below sample 77..............
93	" " "	Next 19 feet below sample 92..............
71	" " Glendale	From top layer, down 25 feet ....
70	" " "	Next 40 feet below sample 71..............
69	" " "	Omitting 3 feet, next 20 ft. below sample 70.
68	" " "	Next 11 feet below sample 69..............
67	" " "	Next 13 feet below sample 68..............
54	Preble Co., Camden	From top layer, down 10 feet ....
53	" " "	Next 20 feet below sample 54..............
52	" " "	Next 20 feet below sample 53..............
51	" " "	Next 12 feet 6 inches below sample 52 ......
50	" " "	Next 12 feet 6 inches below sample 51 ......
103	Warren Co., S. Lebanon	From top layer, down 50 feet ....
102	" " "	Next 40 feet below sample 103.............

Analysis of Rocks of this Formation

	Clermont Co	New Richmond. Wormley, 1869.
	Hamilton Co	Cincinnati. Locke, 1838................
	" "	" Wormley, 1872, "River quarries."

of the Lower Silurian or Hudson River Formation. (Peppel.)

Constituents.					Total.	Remarks.	Serial number of samples.
Silica.	Alumina.	Ferric oxide.	Carbonate of calcium.	Carbonate of magnesium.			
9.30	3.04	1.30	82.50	1.93	98.07	A gap between samples 84 and 85 was not sampled.	83
10.10	3.14	1.30	83.50	1.51	99.55		84
7.86	2.95	0.75	85.60	2.48	99.64		85
13.20	4.46	1.30	78.05	2.36	99.37	Total section sampled was 145 feet 6 inches	86
32.80	9.12	2.30	49.65	4.12	97.99		87
32.34	8.69	2.45	50.00	4.15	97.63		88
31.60	10.97	2.85	47.25	5.00	97.67		89
45.36	15.24	3.90	26.25	5.06	95.81		90
28.94	10.00	2.90	52.95	2.65	97.44	10 feet from bottom of 65 to drainage.	66
31.80	10.95	3.25	48.40	3.25	97.65		65
36.00	12.36	3.70	41.60	3.57	97.23		58
29.96	9.55	3.05	49.80	3.06	95.42		59
33.86	11.56	3.50	44.00	3.72	96.64		57
26.10	8.44	2.30	56.80	3.58	97.22		56
34.80	11.62	2.80	42.50	4.72	96.44		55
18.74	6.80	1.90	68.50	3.06	99.00	Near top of H. R. Formation.	91
38.80	14.64	4.10	35.00	3.07	95.61		78
22.70	9.00	2.00	60.40	3.13	97.23		79
33.50	12.00	3.70	43.35	2.65	95.20	A gap of 12 feet was not sampled between Nos. 75 and 77.	76
20.66	7.74	2.10	63.70	3.58	97.78		72
30.28	10.30	2.40	49.60	4.46	97.04		73
33.08	10.78	2.80	46.60	4.19	97.45		74
30.00	9.80	2.30	51.45	3.75	97.30	Section represented in full is 148 feet thick.	75
36.84	11.14	3.30	40.90	4.15	96.33		77
38.00	13.80	2.80	38.72	3.30	96.62		92
25.04	9.38	2.80	58.08	3.02	98.32		93
24.26	7.99	2.65	60.40	2.80	98.10	A gap of 3 feet 65-68 feet below top of quarry was not sampled.	71
29.80	10.05	2.55	50.95	4.40	97.75		70
38.30	13.35	3.65	35.90	4.84	96.04		69
31.30	11.47	3.25	45.00	6.10	97.12		68
52.38	18.64	4.60	13.20	5.36	94.18		67
9.70	4.31	0.85	80.40	3.09	98.35	Total rock face-sampled, 75 feet.	54
15.28	6.05	1.25	70.35	5.34	98.27		53
13.16	5.15	0.75	75.90	3.30	98.26		52
14.60	5.25	1.55	72.30	4.37	98.07		51
11.62	4.84	0.80	76.70	4.54	98.50		50
23.30	9.11	2.05	60.08	3.28	97.82	Total rock face sampled, 90 feet	103
29.00	9.57	3.15	52.63	3.52	97.87		102

Compiled from Various Sources.

10.80	1.40	....	86.60	1.13	99.93		
2.57	3.15	....	90.13	1.11	98.89	Water 1.13	
23.48	3.40	....	71.30	1.89	100.07		

Uses.— The chief present use of the limestones of this formation is for building purposes, but is only local. A little of it is burned for lime, giving a very dark and a very hot lime. It has been burned at Cincinnati, and a few miles north of West Union, Adams county, for many years. A small amount is crushed for road metal, mainly by hand.

The fact that it is low in magnesia makes it available for portland cement. The magnesia is found to be highest where the shale layers are thickest, hence we can be reasonably sure that most of the magnesia is brought into the sample by the shale. The fact that the shale is usually silicious, and that the ratio of silica to alumina is usually about that desired for portland cement manufacture also recommends it.

By an inspection of the analyses of Table I, it will be seen that in the section sampled at any one geographical point, the greater portion could be used, by casting out a small proportion of the shale, and still maintain the per cent. of magnesia within that allowable in burnt cements —i. e., three per cent., which is equivalent to about 4.5 per cent. magnesium carbonate in the raw or unburnt mixture.

The economic situation to be considered in using this stone as the basis of a hydraulic or portland cement industry is not as favorable as the inherent chemical quality of the limestone itself. The distance from the fuel supply is its chief drawback. Fuel and limestone, both of proper composition, are the two fundamental needs of a cement industry. Neither, without the other, makes the most favorable situation. The fuel can be transported more readily than the stone, and in fact many plants—in fact, perhaps the majority—are situated so that they must transport the fuel from fifty to three hundred miles. This can be considered in no other light than a very heavy handicap, unless the geographical location of the plant gives it a counterbalancing advantage in marketing its output—a large home market or a fine center for distribution.

The location of the Hudson River group limestones in the southwestern corner of Ohio is neither the best nor the worst in the matter of access to fuel and to markets. The haul of the fuel runs from thirty to one hundred miles. Part of the area is available for river transportation, and the finest fuel of the Pittsburg and Kanawha districts is thus reached with low transportation costs. The other points would depend on all-rail transportation, and probably on the coals of southern Ohio.

In summing up, this district may be said to be a possible, *but at present not a commercially attractive* location. How soon the shifting of conditions as to markets and fuel-supply may change this judgment, cannot be foretold. The fact of chemically suitable material on which to found the industry cannot be gainsaid.

THE CLINTON FORMATION.

The Clinton limestone is a formation lying between the topmost of the Hudson River series, the Medina shales, and the bottom member of the Niagara series, the Dayton limestone. Its thickness is not great, from ten to fifty feet. It occurs generally where the areas of Niagara and Hudson River group formations come in contact, forming a narrow or fringing border. So far as is known, there is no large area in the state where it is the superficial formation, but the collective area of its exposures in Butler, Preble, Montgomery, Miami, Clark, Greene, Warren, Clinton, Highland and Adams counties (see map, Chapter I) must aggregate several hundred square miles. Wherever erosion has cut through the Niagara into the Hudson River series, the Clinton may be found.

Physical Character.—It is the most irregular formation in the western half of the state in color, bedding and composition. Yet with all its irregularities it is very readily recognized by its coarsely crystalline character. The upper layers are always rich in crinoidal stems. It is further marked by a red stratum, which in a few localities becomes rich enough in iron to deserve the name of ore.

Chemical Character.—The few analyses of the Clinton limestone, which had been made when this survey was undertaken, usually gave very high percentages of calcium carbonate, low percentages of magnesium carbonate, and oftentimes very low silica and alumina, indicating that the formation was one of the best sources of high-calcium lime in Ohio. All of the older writers had called attention to these peculiarities, but none of their samples were so specifically described as to make it apparent that they represented any large or accessible deposits, which might be opened up to industrial uses. It was therefore determined to study this formation at a number of points with a view to finding if it really was capable of use in a large way as a portland cement stone, or for other chemical purposes like sugar manufacture.

The results of this investigation have been given county by county and are here collated, the new work being given first and the compiled analyses following:

TABLE II.—Analysis of the Limestones

Serial number of samples.	Locality of quarry.	Thickness and relative position of strata represented by this sample
125	Clark Co., Enon	From top, down 8 feet
126	" " "	Next 6 feet below sample 125
110	Clinton Co., Lumberton	From top, down 12 feet
111	" " "	Next 7 feet below sample 110
104	" " Wilmington	From top, down 9 feet
105	" " "	Next 9 feet below sample 104
106	" " "	Next 7 feet below sample 105
114	" " Lynchburg	From top down 8 feet 6 inches
115	" " "	Next 6 feet below sample 114
116	" " "	Next 5 feet below sample 115
127	Greene Co., Yellow Springs	From top, down eight feet
128	" " " "	Next 8 feet below sample 127
129	" " " "	Next 9 feet below sample 128
132	" " New Jasper	From top, down 5 feet
131	" " " "	Next 7 feet below sample 132
130	" " " "	Next 7 feet 6 inches below sample 131
43	Miami Co., Piqua	Top, down 8 feet
36	" " "	Next 6 feet 4 inches below sample 43
47	Montgomery Co., Centerville	Top, down 9 feet
48	" " "	Next 8 feet below sample 47
63	Preble Co., Eaton	From top, down 28 inches
62	" " "	Next 36 inches below sample 63
61	" " "	Next 42 inches below sample 62
60	" " "	Next 48 inches below sample 61
35	" " New Paris	From top, down 2 feet

Analysis of Limestones of this Formation

a	Adams Co., Lick Fork	Locke, analyst,	1837
b	Clark Co., New Carlisle	Wormley, "	1869
c	" " " "	Lord, "	
d	Greene Co., Osborn	Lord, "	1888
e	" " "	Lord, "	1888
f	Miami Co., Piqua	Lord, "	1888
g	" " Ludlow Falls	Wormley, "	1870
h	Montgomery Co., Centerville	Wormley, "	1870
i	" " Dayton	Locke, "	1838
j	" " "	Wormley, "	1870
k	" " Centerville	T.H.Norton, "	
l	Preble Co., Eaton	Wormley, "	1869

Of the Clinton Formation

Silica.	Alumina.	Ferric oxide.	Carbonate of calcium.	Carbonate of magnesium.	Total.	Remarks.	Serial Number of samples.
0.84	1.32	0.42	83.40	13.93	99.91		125
1.00	0.60	1.70	54.08	42.42	99.80		126
1.80	0.85	0.75	93.90	2.78	100.08		110
17.80	4.18	3.30	45.58	29.94	100.80		111
2.10	2.21	3.07	87.07	4.92	99.37		104
2.32	1.53	1.15	83.77	10.20	98.97		105
10.04	3.10	2.60	49.70	33.48	98.92		106
2.96	0.81	0.75	94.48	0.98	99.98		114
19.10	1.04	0.90	77.45	1.24	99.73		115
8.70	2.51	1.55	74.78	12.09	99.63		116
4.28	1.37	1.51	67.21	25.04	99.41		127
1.53	1.30	0.90	77.35	19.45	100.53		128
0.72	0.45	1.95	68.20	28.44	99.76	Near bottom of Clinton.	129
10.32	5.73	4.07	71.78	7.36	99.26	Red crystalline stone.	132
9.30	4.38	0.60	81.92	3.24	99.44	Light colored stone.	131
2.54	0.69	1.71	75.27	20.60	100.81	Brownish gray stone.	130
1.40	1.14	trace	87.50	9.40	99.44	Ohio Marble Co.'s.	43
0.46	0.59	0.17	82.35	16.76	100.33	Ohio Marble Co.'s.	36
4.02	2.28	0.52	88.95	3.59	99.36	Covered by 9 feet 6 inches of stone.	47
0.50	0.48	1.00	90.95	7.06	99.99	Shale immediately underneath.	48
1.02	1.22	0.22	95.35	2.21	100.02		63
0.92	1.00	0.10	95.20	2.40	99.62		62
0.58	0.47	0.25	91.85	6.50	99.65		61
0.74	0.62	0.40	94.45	4.07	100.28		60
1.52	1.00	0.60	95.10	1.80	100.02		35

Compiled from various sources.

2.00	1.60	....	93.00	3.04	99.64	Flinty limestone.	a
0.40	....	....	95.60	3.93	99.93		b
0.83	0.29	....	96.80	2.07	99.99		c
1.64	0.36	....	97.09	0.82	99.91	Haddock's best.	d
0.70	0.41	....	97.14	1.21	99.46	" rejected.	e
0.45	0.26	....	95.03	4.35	100.09	Harrington farm.	f
0.80	1.20	....	91.30	6.51	99.81	Smith's quarry.	g
0.85	0.40	....	86.30	11.34	98.89		h
2.60	0.53	....	92.30	1.10	96.53	Combined water 1.08	i
3.47	0.55	....	90.03	5.71	99.76		j
3.58	1.80	....	87.07	7.37	99.82		k
0.35	0.80	....	85.21	13.56	99.92		l

The wide range of composition is apparent. There is much stone of the character noted by the earlier observers. There is much that is far from it. In the case of some few of the samples, it is possible that wrong correlations have been made and analyses thus included which really belong in other tables. This is not thought to be the case.

It is seen that in many cases the carbonate of calcium is diluted with sand and clay, as in samples 115 and 131, but more often the dilution is with carbonate of magnesium as well, as in samples 125, 126, 105, 127, 130, etc., and in many others the increase in magnesia and clay and sand was simultaneous, as in 111, 106, etc.

In summing up, we may say that the Clinton formation contains, in many places, limestones of very great purity, but that the formation is too irregular in composition, both from layer to layer and from area to area, to make it, *per se*, valuable for high-calcium lime. That is, the possession of an area of Clinton limestone is not to be considered as a guarantee of having an area of high-calcium stone, or even of low-magnesium stone. It can only be considered as a possible—not improbable —source of such stone, and the burden of proof rests strongly on the would-be user. Nothing less than thorough sampling, layer by layer, and acre by acre, would justify the establishment of any large industry, dependent on accurate chemical control, on this formation. At the same time, it is fully believed that there are many places in the Clinton areas of Ohio where such locations can be found by careful testing.

Uses.—The Clinton limestone is worked to only a small extent. The formation in the majorlty of places makes a very hot lime, not desired by the quicklime trade, so that this branch of the industry does not flourish. It is sometimes used; for instance, the Ohio Marble Company of Piqua sell a part of their stone to other parties who burn it for lime. For building stone also, it does not seem well suited. At Wilmington, the Ballard quarry produces a fine bridge stone, which can be worked with economy. This is the only place which can be cited where the Clinton stone seems a really desirable stone from the quarryman's standpoint. It is used for crushed rock and railroad ballast at a number of points, viz: Centerville, Wilmington, New Jasper, Lynchburg.

At Piqua, the Ohio Marble Company are grinding the lower courses of the Clinton, and selling it as marble dust, for various purposes. The stone is nearly white, showing beautiful, large, slightly pink dolomite crystals, and practically free from shale.

For portland cement, it has a possible use, in some of the exposures cited. Its composition is often favorable. High-calcium stone is not essential, if the magnesia is low. Many of the silicious forms would be admirably adapted to this industry, furnishing nearly all the silica and alumina that the cement would require, and hence requiring the addition [illegible] little or no clay.

However, the economic considerations which must receive a search-analysis in any profitable and successful mineral industry are against the Clinton locations to some extent. They are all distant from fuel; i. e., it would require railroad transportation of from thirty to one hundred miles. This is by no means prohibitive, but it is not as favorable as the situation which some other localities enjoy.

One other consideration which affects prejudicially the Clinton as a portland cement material is the comparatively few places where it is really the superficial deposit. Many of its best exposures occur where the overlying Niagara would have to be removed to the extent of from several feet up to fifteen or twenty. This is of course a severe handicap. It necessitates the finding of a market for the cap rock which must be moved. It would have to pay for its own handling, but the profitable moment for handling could not be chosen—it would have to be kept out of the way, either at a profit or a loss. Also, if the attempt were made to mine the Clinton without taking out the Niagara, the question of drainage might become serious.

Also the stripping of the Niagara from the Clinton would leave a lot of small fragments of magnesian stone, which would be always likely to get into the material below, and thus make an element of fluctuation in the composition.

It seems likely from all of these considerations, that the ~~portland~~ cement industry will develop at other points in preference to Clinton ~~areas~~. Yet it is beyond question feasible to establish an industry upon the limestone. It does not now seem the best opportunity which the state affords.

THE NIAGARA GROUP.

The Niagara group is the name given to the lower portion, usually about one-half, of the rocks of the upper Silurian age in Ohio. The name has been abandoned elsewhere, and may be abandoned later in Ohio, when the various sub-formations are clearly worked out and correlated. The rocks of this age in Ohio are found in two areas, a northern and southern, which do not communicate, and the formations or sub-formations shown in the south are probably not all clearly distinguishable in the north.

The group is predominantly calcareous everywhere in Ohio. Limestones constitute the bulk of the rocks, and the majority of the sub-formations. Some few thin shales and sandstones make their appearance locally, but the shale and clay material is unimportant in total amount-

The limestone strata are divided into a number of different sub-formations, which are lithologically distinct at the points of their most characteristic development, but which become hard to recognize else where. It is difficult therefore to clearly place all of the samples and analyses here collected, in their proper stratigraphical order. Without doubt, errors in correlation have been made. However, the general character of the stones of this group is chemically quite uniform, even when the rocks are lithologically markedly different, and when their fossil life is also characteristic and dissimilar. As the general purpose of this work is chiefly industrial, and specially for industries based on chemical processes, any errors in correlation which may have been made will not affect their value to any serious degree.

The limestone subdivisions now recognized in this formation in southern Ohio are the Dayton limestone, the West Union limestone, the Springfield limestone and the Cedarville limestone.

The Dayton Limestone.—This is a very hard, dense limestone of light blue-gray or gray color, which often is marked by the occurrence of iron pyrites in crystalline form, scattered in little grains through the rock. It is greatly valued for a building stone, and though hard to dress, it makes cut stone equal to any which can be made from limestone in durability, strength, and uniformity of color. The stratum in Dayton, where it has been largely worked for years, is only five to ten feet in thickness. It is not a uniformly occurring bed—its area in any one locality is small, but its character is so marked that it is recognizable wherever it is found.

The composition of the Dayton stone in its characteristic exposures is highly calciferous, ranging from 85 to 95 per cent. of carbonate of calcium, with low magnesium.

The Dayton stone is not used for lime, because of the limited amount of it, and its value for building purposes, and the abundance of other stone nearby which makes acceptable lime. Its almost sole use is for building stone, in Montgomery, Miami, Clark, Greene, and Clinton counties.

The West Union Limestone.—The West Union stone, or "Cliff" limestone of the older reports, is a massive ledge overlying the shales which generally cover the Dayton stone, or which in its absence lie on the Clinton. This formation is developed chiefly in the southern portion of the field, in Adams and Highland counties, where it has a thickness of twenty, forty, or even eighty feet in its southern exposures. It is a massive, heavy-bedded, generally impure limestone, magnesian in character, but seldom attaining the dolomite composition shown by the next stone above it. This stone is used somewhat for building purposes and sparingly for lime. It is nowhere the basis of a large industry.

The Springfield Limestone.—This valuable stratum is the one which gives character and continuity to the Niagara group as a group. Like the lower Niagara, the upper portion of the group is even bedded, but unlike it the beds are of great thickness, so as a rule it is not adapetd to the economic quarrying of building stone. It is, however, in a few localities used to some extent as a material for construction. Its main value, however, lies in the production of lime. The well-known white lime of Springfield comes from this horizon.

The physical character is almost always massive and earthy, and has a narrow range in color, nearly always being a buff, with occasional quarries showing a brownish yellow.

In chemical composition it is always close to a pure dolomite. The silica and alumina seldom reach three per cent. The lime made is usually almost a pure white, with a pink tint in many locations.

The Cedarville Limestone.—This formation is the cap rock of Springfield stone, and while just as valuable for lime burning on account of its thinner, friable slabs, and porous structure, it is less valuable for common building stone. These two formations have an identical composition, both being nearly pure typical dolomites. Hence it has been impossible in this report to distinguish clearly between them in the various samples taken and the various analyses quoted. Suffice it to say that the upper portion of the Niagara in both southern and northern portions of the state, while lithologically and stratigraphically separable into two beds, is for lime and chemical uses inseparable.

The two formations are usually worked together. The Springfield quarries, making the famous Springfield lime, are using the Cedarville or cap rock for it, and using the Springfield stone below partly for building stone and partly for lime. At Cedarville, also, both formations are worked and the upper is best suited to the lime kiln, by physical structure, but not by composition.

The uses of these two formations is chiefly for lime burning, though they are quarried for building stone and even for crushing at some points. They are the basis of large lime industries in the following points:

Port Williams, Greene county.
Cedarville, Greene county.
Yellow Springs, Greene county.
Springfield, Clark county.
Gettysburg, Darke county.
Carey, Wyandot county.
Fostoria, Seneca county.
Gibsonburg, Sandusky county.
Woodville, Sandusky county.
New Paris, Preble county.
Lewisburg, Preble county.
Covington, Miami county.

It is used at Springfield and a number of other points for road metal and flux.

Chemical Composition.—The composition of the limestones of the Niagara group in fifteen counties and thirty-three localities is given below. The total number of samples analyzed number eighty four. It has not been possible to classify them accurately with regard to their formations and hence no attempt has been made to group the analyses of each formation by themselves. However, where any clue to the formation is at hand it has been indicated in the remarks.

Table III—Analyses of the Limestones

Serial number of samples.	Location of quarry.	Thickness and relative position of stratum represented by this sample.
80	Adams Co., West Union	From top, down 4 feet 6 inches
81	“ “ “ “	Next 6 feet below sample 80
82	“ “ “ “	Next 8 feet below sample 81
96	“ “ Peebles	From top, down 12 feet
94	“ “ Newport	From top, down 21 feet
95	“ “ “	Next 10 feet below sample 94
109	Clinton Co., Lumberton	Top, down 5 feet 6 inches. On the Clinton
107	“ “ Wilmington	Top, down 5 feet 6 inches. On the Clinton
113	“ “ Lynchburg	4 feet 6 inches, under 4 feet 6 inches shale
31	Darke Co., Gettysburg	From pile of already quarried rock
32	“ “ “	“ “ “ “ “ “
108	Greene Co., Port Williams	From top, down 7 feet
134	“ “ New Jasper	From top, down 6 feet
133	“ “ “ “	Next 2 feet 6 inches below sample 134
119	Highland Co., Leesburg	From top down 10 feet, underlain by 2 feet of shale
120	“ “ “	Next 6 feet below shale of sample 119
121	“ “ “	Next 13 feet below sample 120
99	“ “ Hillsboro	From top down 23 feet—Rucker's Quarry
100	“ “ “	Next 24 feet below sample 99
101	“ “ “	Next 14 feet below sample 100
30	Mercer Co., Celina	From top down 4 feet
44	Miami Co., Piqua	From top, down 16 feet 6 inches
45	Montgomery Co., Centerville	Stripping soft stone, 5 feet 6 inches
46	“ “ “	Next 4 feet below sample 45
34	Preble Co., New Paris	From top, down 10 feet
33	“ “ “ “	Next 19 feet 8 inches below sample 34

Analyses of Limestone of the Same Formation

a	Adams Co., West Union	Wormley, 1869, “Cliff” Limestone
b	Clark Co., Springfield	“ 1869–1870, Thompson's Quarry
c	“ “ “	“ “ “ Moore's Quarry
d	“ “ “	“ “ “ Frey's Quarry
e	“ “ “	“ “ “ “ “
f	“ “ “	“ “ “ “ “
g	“ “ “	“ “ “ Sintz's Quarry
h	“ “ “	“ “ “ Petticrew's Quarry
i	“ “ “	“ “ “ “ “
j	“ “ “	“ “ “ “ “
k	“ “ “	N. W. Lord, 1886–1887, “ “
l	“ “ “	“ “ “ “ “ Moore's Quarry
m	“ “ “	“ “ “ “ “ Frey's Quarry
n	“ “ “	“ “ “ “ “ McCarty's Quarry
o	“ “ “	“ “ “ “ “ Sintz's Quarry
p	“ “ “	“ “ ” “ “ Holcomb's Quarry
q	“ “ “	“ “ “ “ “ “ “
r	Darke Co., New Madison	Wormley, 1870, Northrop's Quarry
s	“ “ Greenville	“ “ Gard's Quarry
t	“ “ “	“ “ Bierly's Quarry

Of the Niagara Formation

Constituents.					Total.	Remarks.	Serial number of samples.
Silica.	Alumina.	Ferric oxide.	Carbonate of calcium.	Carbonate of magnesium			
4.46	1.83	1.91	51.90	40.45	100.55		80
17.80	2.39	1.87	44.00	33.78	99.84		81
24.56	3.06	2.80	39.50	29.30	99.22		82
14.32	1.70	2.30	56.20	24.94	99.46	Probably belongs just below 82.	96
14.80	5.62	2.34	71.40	3.87	98.03		94
16.84	1.78	1.36	76.80	2.64	99.42	Bottom of sample at R. R. level.	95
1.94	1.20	trace	94.42	2.19	99.75	Dayton formation.	109
3.00	0.97	2.47	63.09	30.20	99.73		107
4.88	1.52	3.66	64.55	25.51	100.12		113
0.88	0.84	....	54.70	43.38	99.80		31
0.60	0.70	....	55.50	43.68	100.48		32
0.60	0.76	....	54.50	43.33	99.19	Used for lime exclusively.	108
5.70	2.20	1.20	72.20	18.25	99.55	"Dayton" limestone.	134
9.16	2.69	3.25	54.43	30.42	99.95	Dark colored limestone.	133
4.10	1.32	1.10	52.63	41.08	100.23	Yellowish stone.	119
2.42	0.78	1.78	53.70	41.26	99.94	Darker than above.	120
2.30	0.95	1.55	53.63	41.60	100.03	Blue hard stone, underlain by shale.	121
1.88	0.86	trace	54.10	43.24	100.08	"Cedarville" stone (?).	99
9.88	3.65	0.45	50.90	34.78	99.66	"Springfield" stone (?).	100
30.12	4.30	0.80	40.20	23.50	98.92	"West Union" stone (?).	101
1.14	0.52	trace	54.80	43.10	99.56		30
6.24	2.52	1.00	59.40	31.04	100.20	Overlying the Clinton.	44
24.20	11.03	1.45	36.65	24.24	99.57	Talbot quarry.	45
2.04	1.05	0.15	93.25	2.82	99.31	"Dayton" limestone.	46
2.50	1.32	trace	67.00	29.32	100.14	Hard, blue, well bedded.	34
18.20	1.89	0.15	54.80	25.80	100.84	Flinty—just on top of Clinton.	33

Compiled from Various Sources.

18.80	2.20	....	42.80	34.79	98.59		a
8.26	0.70	....	50.90	39.77	99.63		b
4.90		....	46.40	47.53	98.83		c
3.10	0.30	....	53.70	43.13	100.23	Bottom rock.	d
0.10	0.20	....	54.70	44.93	99.93	Middle rock.	e
1.50	1.00	....	54.70	42.37	99.57	Top rock.	f
7.60	3.10	....	49.70	39.20	99.60	Building stone.	g
1.30	1.80	....	55.40	41.48	99.98	Middle bed.	h
1.40	2.70	....	53.90	41.90	99.90	Top bed.	i
0.10	1.70	....	55.10	43.05	99.95		j
0.65	0.56	....	54.13	44.37	99.71	Average of many analyses	k
0.66	0.42	....	53.51	44.96	99.55	Average sample.	l
1.55	0.39	....	53.88	43.79	99.61	Average sample.	m
0.59	0.39	....	53.77	44.76	99.51		n
0.68	0.37	....	53.92	44.99	99.96		o
1.37	0.54	....	53.44	44.49	99.84	Lime rock.	p
7.37	0.96	....	50.13	40.64	99.10	Building stone.	q
2.70		....	51.70	45.26	99.66		r
2.20		....	51.30	45.72	99.22		s
4.60		....	44.60	50.11	99.31		t

Analyses of Limestone of the Same Formation

Serial number of samples.	Location of quarry.	Thickness and relative position of stratum represented by this sample.
u	Darke Co., Greenville	Orton,
v	Greene Co., Yellow Springs	Wormley, 1869, Sroufes' Quarry
x	" " " "	" " " "
y	" " " "	Lord, 1888, Irvin's Quarry
z	" " " "	" " " "
aa	" " Cedarville	" " Ervin's Quarry No 1
ab	" " "	" " " " No. 2
ac	" " "	Wormley, 1869, Best "Cincinnati" stone
ad	" " Xenia	" " McDonald's Quarry
ae	Highland Co., Lexington	" 1869–1870 Pope's Quarry
af	" " Leesburg	" " " Wright's Quarries
ag	" " Hillsboro	" " "
ah	" " "	" " " Trimble's Quarry
ai	" " "	" " " " "
aj	Miami Co., Covington	N. W. Lord, 1887, Rhule's Quarry
ak	" " Brant	" " " Corey's Quarry
al	Montgomery Co., Wayne Tp.	" " " Wilson's Quarry
am	" " " "	" " " " "
an	" " " "	" " " " "
ao	Ottawa Co., Genoa	" " " 1887–1888, Newman's Quarry
ap	" " "	" " " " " " "
aq	" " "	" " " " " Wyman & Greggs Quarry
ar	" " "	N. W. Lord, 1887-1888, Habberle's Quarry
as	" " "	" " " " " Holt's Quarry
at	Preble County, Eaton	Wormley, 1870
au	" " New Paris	Lord, 1887–1888, Dwyer's Quarry
av	" " " "	" " " " "
aw	" " " "	" " " Smith's Quarry
ax	" " Lewisburg	" " " Disher's Quarry
ay	" " "	" " " " "
az	" " "	" " " Turner's Quarry
ba	Sandusky County, Woodville	N. W. Lord, 1887, Rancamp's Quarry
bb	Seneca Co., Fostoria	" " " "
bc	" " "	
bd	Shelby Co., Sidney	Wormley, 1870, Dugan's Quarry
be	" " "	" " " "
bf	Wood Co., Bowling Green	N. W. Lord, 1887–1888, Thurston's Quarry
bg	" " Rising Sun	" " " " " Wyman, North & Co.
bh	" " Luckey Station	" " " " " Wyman, Gregg & Co.

Compiled from Various Sources.

Constituents.					Total.	Remarks.	Serial number of samples.
Silica.	Alumina.	Ferric oxide.	Carbonate of calcium.	Carbonate of magnesium			
0.61	0.37	....	61.33	37.68	99.99		u
0.40	2.00	....	54.75	42.23	99.38	Best stone.	v
5.40	1.40	....	51.10	41.12	99.02	Blue building stone.	x
0.72	0.51	....	53.98	44.56	99.77	Average of lime rock.	y
5.65	0.76	....	50.75	41.86	99.02	Average of building rock.	z
0.58	0.57	....	53.95	44.62	99.72		aa
0.88	0.53	....	53.90	44.58	99.89		ab
0.72	1.00	....	54.90	43.35	99.97		ac
2.20	2.00	....	84.50	11.16	99.86	"Dayton" stone.	ad
3.57	0.90	....	49.76	45.77	100.00	"Springfield" stone (?).	ae
1.60	2.20	....	54.10	41.77	99.67	" "	af
2.60	3.20	....	62.60	31.32	99.72	"West Union" limestone	ag
13.30	2.00	....	35.57	49.00	99.87	"Springfield" stone.	ah
0.40	1.80	....	54.25	43.23	99.68	"Cedarville" stone	ai
0.85	0.40	....	54.14	44.90	100.29		aj
0.32	0.40	....	54.80	44.01	99.53		ak
0.80	0.83	....	54.30	43.69	99.62	Best stone, first quarry.	al
0.39	0.47	....	54.47	44.73	100.06	Best stone, second quarry	am
4.00	1.13	....	51.97	42.07	99.17	Rejected stone, " "	an
0.04	0.23	....	55.97	44.27	100.51	Cap rock.	ao
0.22	0.51	....	53.04	46.01	99.78	Bottom rock.	ap
0.23	0.16	....	54.30	45.14	99.83	Main rock.	aq
0.28	0.42	....	55.59	43.67	99.96	Main rock.	ar
0.24	0.44	....	54.61	45.05	100.34	Main rock.	as
9.40	4.40	....	49.75	35.87	99.42	Lime rock.	at
0.61	0.37	....	61.33	37.68	99.99	Upper strata.	au
1.23	0.38	....	67.51	30.84	99.96	Lower strata.	av
2.21	0.56	....	67.00	29.26	99.03	Lower strata.	aw
0.60	0.60	....	55.20	43.28	99.68	Selected sample.	ax
0.89	0.45	....	54.58	43.93	99.85	Averaged sample.	ay
1.31	0.94	....	52.70	43.96	98.91	Averaged sample.	az
0.31	0.39	....	53.50	45.79	99.99		ba
0.42	0.28	....	56.41	41.98	99.09		bb
0.37	0.34	....	54.46	44.35	99.52		bc
trace	1.60	....	55.00	42.92	99.52	Burnt for lime.	bd
0.20	0.50	....	54.40	44.58	99.68	" " "	be
1.53	0.40	....	53.98	43.25	99.16	Largely used for lime.	bf
0.57	0.63	....	53.21	45.37	99.78	" " " "	bg
0.43	0.35	....	54.20	44.44	99.42	" " " "	bh

A study of this table shows:

First: That the Dayton stone, in a considerable number of exposures, is a high-calcium stone, ranging even to 94 per cent. calcium carbonate—cf. 109, 134, 46.

Second: That stone on the same horizon—i. e., just above the Clinton—have been found in a few places, showing magnesian character—cf. 44, 33, etc.

Third: That the bedded limestones, lying next above the Niagara shale, and used chiefly for building stone, crushing, ballast, etc., are in all cases magnesian, but not dolomites—cf. 101, 80, etc.

Fourth: That the top of the series, consisting of the two principal limestone formations, present the most wonderful regularity and constancy of composition. They are either pure dolomites, or if diluted with sand or clay, they still remain dolomitic. No finer body of pure limestone can be found anywhere than the great body of these two formations which cover many hundreds of square miles in the west half of the state.

Uses. These have been mentioned repeatedly in different connections. Briefly, they are in order of importance:

First: White Lime. This group is the basis of a larger industry in lime than any other in the state. The product is always of the mild or slow type, but is unsurpassed for whiteness, plasticity, covering qualities, and general good working qualities.

Second: Building Stone. The lower members furnish a magnificent stone for cutting, and are the basis of a large industry in the southwestern part of the state. Also, much stone for ordinary range work is obtained from the lower half of the group and some considerable from the upper half as well.

Third: Crushing for Ballast, Concrete, etc. No large quantity of stone for this purpose comes from this formation. Some flinty layers occur which are fit for no other purpose and are used, especially when they cover more desirable beds, but compared to the great industries mentioned on the Corniferous and Waterlime, the crushed stone industry is small and likely to remain so. The softness and porosity of many parts of the stone are unfavorable to this industry, but exceptionally favorable to the burning of lime.

Fourth: Cements. No hydraulic lime, natural cement or portland cement is made in Ohio from rock of this group, so far as is now known.

The Dayton stone is in a few places of remarkable purity—eminently satisfactory for portland cement. Where this quality of stone lies on the Clinton direct, as at Lumberton and Centerville, and where the Clinton also presents a high-calcium phase, the combined thickness of the two materially improves the chance of working them profitably; also the danger of contamination of the lower by chips of the upper is removed.

It cannot be fairly claimed, however, that there is any large prospect of finding all of these conditions in numerous places, or that the Dayton stone has by itself much of a future in the cement industry.

None of the strata above the Dayton stone show the least likelihood of being useful in this field.

THE LOWER HELDERBERG OR MONROE FORMATION.

This group is much simpler than the Niagara, consisting of an upper, principal stratum of limestone of considerable thickness, underlain in a few localities by a thin bed of sandstone. The sandstone in turn, or in its absence the upper limestone, is underlain by a thin-bedded limestone which becomes even shaly in places, though still remaining calcareous. The only member of the group which is of importance in the connection here discussed is the upper member, which has recently been given the name Lucas limestone. The Lucas limestone is the stratum of the Lower Helderberg or Waterlime group which figures in previous reports in connection with the lime and stone industry.

The area covered by the formation is considerable. It is confined in Ohio to the west and northwest part. In Paulding, Van Wert, Putnam, Allen, Lucas, Wood, Hancock, Harding, Wyandot, Logan, Union, Champaign, and Madison counties, it is the predominating superficial formation; in some cases, the only one. In Mercer, Auglaize, Henry, Ottawa, Sandusky, Seneca, Marion, Delaware, and Fayette it is well represented, but not predominant. The total area covers many thousand square miles.

In the most of this area, the topography is flat and uninteresting and the exposures of the stone are few. The bulk of the openings are made artificially---natural quarry sites such as characterize the lower formations in central and southwestern Ohio are rare.

Physical Character.—This formation is not nearly so regular in its physical character as the preceding, varying from an earthy, dirty-brown, rather soft stone, through a light-gray porous phase, showing large crystals of dolomite, to a hard, dense, bluish stone.

These different physical characters observed are possibly due to different ages or times of depositions, so that a careful tracing of similar physical characteristics might assist in defining each period of deposition throughout the entire height of the Ohio scale of the Waterlime formation.

Chemical Character.—In chemical character it is very regular, varying from a pure dolomite only by the inclusion of sand and clay, generally in very small quantities. In this respect, it is almost identical with the Niagara below it. It is one of the wonderful instances of close adherence to a type composition in a mineral stratum which can be instanced in eological literature. For instance, examination of the subjoined table shows that in ten counties, covering a distance of one hundred and fifty miles or more, all thirty-two samples are uniformly dolomites. The percentage of admixed clay and sand is also very small; in twenty-six out of thirty-six analyses, the silica falls below three per cent., and the combined carbonate of calcium and magnesium will certainly average above ninety-five for the entire lot. In many cases, the total impurity falls below one per cent.

It is difficult for us to see why this formation came by its name,

IV.—Table of Analyses

Serial number of samples.	Location of quarry.	Thickness and relative position of stratum represented by this sample.
27	Allen Co., Lima	From top, down 26 feet
28	“ “ Bluffton	From top, down 12 feet
21	Hancock Co., Findlay	From top, down 9 feet 6 inches—Tarbox & McCall
20	“ “ “	Next 12 feet below sample 21
40	Hardin Co., Kenton	From top down 5 feet—Locey's quarry
41	“ “ “	Next 10 feet below sample 40
122	Highland Co., Greenfield	From top, down 31 feet—Rucker's quarry
123	“ “ “	Next 12 feet below sample 122
124	“ “ “	Next 13 feet below sample 123
117	“ “ Leesburg	From top down 12 feet—Luft's quarry
37	Logan Co., Bellefontaine	From top, down 8 feet—B. S. & Lime Co
38	“ “ “	Next 4 feet below sample 37—B.St.& Lime Co.
39	“ “ “	Next 15 feet below sample 38 “ “
13	Sandusky Co., Fremont	From top, down 12 feet—Gottron Bros. quarry
29	Van Wert Co., Middle Point	From top, down 22 feet—E.H.France's quarry

Analyses of the Lower Helderberg Limestones

a	Allen Co., Bath Tp	Lord, 1887—G. W. Fetter's quarry
b	Fayette Co., Green Tp	Wormley, 1869–1870, Rittenhouse's quarry
c	“ “ Wayne Tp	“ “ “ “ “
d	“ “ “ “	“ “ “ “ “
e	“ “ “ “	“ “ “ “ “
f	Hancock Co., Findlay	Lord, 1887
g	“ “ “	“ “
h	Highland Co., Greenfield	Wormley, 1869-1870—Wright's quarry
i	“ “ “	“ “ “ “ “
j	“ “ Sinking Springs	“ “ “
k	Logan Co., Bellefontaine	“ “ “ Scarf's quarry
l	“ “ “	“ “ “ “ “
m	Lucas Co., Toledo	“ “ “ No locality given
n	“ “ “	“ “ “ “ “ “
o	“ “ “	“ “ “ “ “ “
p	Ottawa Co., Rocky River	Lord, 1887—Kingham's quarry
q	“ “ Limestone Station	“ “
r	Sandusky Co., Fremont	“ “ Noble's quarry.
s	“ “ “	“ “ Gottron Bros. quarry
t	Seneca Co., Fostoria	“ “
u	“ “ “	

Waterlime, for no limestone formation in the state so seldom shows aptitude for making hydraulic lime. It was probably expected, from characteristics shown by beds of the same age elsewhere, that this bed would be of that character; in fact, an effort was once made by the evidence of the three analyses, i, j, and k, to show that the formation was true to its name. But it has long been known that these Toledo samples do not represent the character of the formation at all—in fact, they stand out as the three marked departures from the type in the whole collection.

Of the Lower Helderberg Limestone.

Constituents.					Total.	Remarks.	Serial number of samples.
Silica.	Alumina.	Ferric oxide.	Carbonate of calcium.	Carbonate of magnesium.			
1.40	0.88	trace	54.25	43.36	99.89		27
2.70	1.32	trace	53.00	42.80	99.82		28
0.92	0.52	....	55.50	43.40	100.34		21
1.36	0.96	....	54.90	43.42	100.64		20
3.06	2.10	trace	52.55	42.12	99.83	Buff.	40
1.80	1.04	trace	53.50	43.10	99.44	Blue.	41
1.10	0.46	0.30	55.00	43.44	100.30	Massive layer.	122
1.90	0.64	0.20	54.00	42.72	99.46	Thin, even beds.	123
2.10	0.74	0.20	53.70	42.94	99.68	Thicker, even beds.	124
7.16	2.19	1.05	49.95	39.42	99.77		117
2.00	0.96	0.20	54.70	42.80	100.66	Gray, hard, well bedded.	37
1.24	0.21	0.35	55.30	43.17	100.27	Soft and rotten.	38
2.10	0.99	0.15	54.40	42.92	100.56	Heavy bedded, soft.	39
1.06	0.42	trace	55.65	40.66	97.79	Rejected for lime.	13
1.12	0.52	trace	54.55	43.56	99.75		29

Compiled from Various Sources.

Silica.	Alumina.	Ferric oxide.	Carbonate of calcium.	Carbonate of magnesium.	Total.	Remarks.	Serial number of samples.
1.18	0.14	....	53.69	45.00	100.01	Used for lime.	a
6.00	2.30	....	52.40	38.73	99.43	Used for lime.	b
4.80	2.60	....	53.60	38.30	99.30	" " "	c
3.60	2.20	....	54.00	39.50	99.30	" " "	d
2.80	2.90	....	53.60	40.28	99.58	" " "	e
1.55	0.39	....	53.88	43.79	99.61	Accepted quality.	f
8.00	1.16	....	49.62	40.94	99.72	Rejected for lime.	g
4.43	1.00	....	49.70	44.87	100.00	Lime and building stone.	h
2.44	1.30	....	53.67	42.42	99.83	" " " "	i
0.70	1.50	....	52.87	42.94	99.40	1.39 calcium phosphate.	j
2.80	1.30	....	55.10	40.11	99.31		k
2.70	2.10	....	55.00	39.74	99.54		l
16.76	2.24	....	46.60	32.69	98.29	Hydraulic lime.	m
19.40	1.82	....	44.40	32.69	98.31	" "	n
5.00	1.60	....	52.80	39.65	99.05	" "	o
0.87	0.29	....	54.10	44.27	99.53	15-foot section.	p
0.29	0.25	....	54.12	44.79	99.45	11-foot section.	q
0.74	0.27	....	54.06	45.20	100.27	Used for lime.	r
0.35	0.43	....	55.65	42.29	98.72	" " "	s
0.42	0.28	....	56.41	41.98	99.09		t
0.37	0.34	....	54.46	44.35	99.52		u

Uses. *Building stone, crushed stone, etc.* A great deal of crushed stone and lime comes from the northern or main portion of this formation, and some very fine building stone, as well as lime, from its southern extension. The Greenfield quarries show the building stone at its best.

The eastern border of the formation furnishes the most of the building stone; this is probably the upper part of the formation. The western areas give principally the lower and middle phases of the formation. Some of the principal quarries opened on this formation are located at:

Highland Station, Highland county—Lime and building stone.
Greenfield, Highland county—Lime, building and crushed stone.
Bellefontaine, Logan county—Crushed and building stone.
Lima, Allen county—Crushed stone.
Delphos, Allen county—Crushed stone.
Bluffton, Allen county—Crushed and building stone.
Middlepoint, Van Wert county—Crushed stone.
Waterville, Van Wert county—Crushed and building stone.
Holland, Lucas county—Crushed stone.
Sylvania, Lucas county—Crushed stone.
Stony Ridge, Wood county—Lime.
Sugar Ridge, Wood county—Lime.
Portage, Wood county—Lime and crushed stone.
Luckey, Wood county—Lime.
Fremont, Sandusky county—Lime.
Bellevue, Sandusky county—Lime.
Rocky Ridge, Ottawa county—Lime.
Genoa, Ottawa county—Lime.
Dunkirk, Hardin county—Crushed stone.
Marseilles, Hardin county—Crushed stone.

Lime. While most of the Waterlime will burn to a good lime, some of it is not of a desirable physical character for economic manufacture. The stone breaks up in such fine pieces in quarrying that, according to present practice in burning lime, it would have to be discarded for that purpose. The discarded part might be used for crushed stone, but there would still be the expense of selecting or sorting the stone for lime.

A partial list of the points at which lime is being burned is given in the paragraph preceding.

Cement. The formation is entirely out of the question in this relation, as its uniformly high magnesia is its most well-marked characteristic. Even for hydraulic lime, its use would be limited to occasional rare exposures when the stone carries an unusual amount of impurities in the shape of sand and clay.

THE CORNIFEROUS OR DEVONIAN LIMESTONES.

These limestones mark the summit of the great limestone beds of Ohio. Up to this time, marine strata had been predominantly calcareous. Even when the seas were troubled and muddy, shaly limestones or calcareous shales were deposited, and only in a few localities do we find sandstone or pure clay-shales occurring. The long period of magnesian limestone deposition, represented by the Niagara and Monroe formations, was broken, or at least altered, in the Devonian period, and while limestones still were deposited for a time, they no longer were consistently or regularly magnesian, and in some places they became highly calciferous.

The Devonian limestones occupy a relatively small area in Ohio compared to all of the preceding groups except the Clinton. They form a broad band, ten to twenty-five miles wide, and one hundred and fifty miles long, through Pickaway, Franklin, Delaware, Marion, Crawford and Wyandot, Seneca, Sandusky and Erie counties, and the Lake Erie islands. They are missing on the Cincinnati axis, but on the other side of it they come in again, forming a crescent-shaped band, ten to twenty-five miles wide, running through Paulding, Henry, Wood, and Lucas counties. The total area exposed is not more than one-fourth or one-fifth of the area of the Niagara or Monroe.

The group consists of two distinct and fairly well marked formations: the bottom or Columbus limestone, from sixty to one hundred and ten feet in thickness, and the Delaware limestone, about thirty feet in thickness. The two formations are both found in the same quarry in a number of places, but not in the majority of exposures.

The Columbus formation is a heavy-bedded, generally buff-colored limestone, crystalline in some layers, but generally giving an appearance of earthiness which a close inspection does not justify. It is not closely adherent to a type in composition. In nearly all localities it contains beds of low-magnesia high-calcium stone. In some places, as at Marblehead, these beds are the top of the formation; in others, as at Columbus, they are the bottom; chert or flint in nodules, or bands of nodules, is common in all parts of the formation.

The Delaware formation is a well-bedded, but rather thin, blue stone, the lower layers of which are admirable for building purposes, and the upper layers of which are very thin and often shelly or shale-like. The formation is also wavering in composition, being sometimes magnesian and sometimes not.

Both formations are largely worked, and as they had not been examined by previous writers with as much care as had been devoted to the Niagara and Lower Helderberg, they were given more attention in this instance. Also it was known that the formation shows phases which seemed promising for cement, and they were sampled frequently to see to what extent these phases occur.

Chemical Composition.—The composition of the stone in eleven counties and from fifteen locations is given below in sixty analyses, of which twenty-three are new and made from carefully sampled sections.

Analyses of the

Serial number of samples.	Location of sample.	Thickness and relative position of stratum represented by this sample.
26	Defiance Co., Defiance........	From top, down 17 feet—Snyder Bros. quarry.
5	Delaware Co., Delaware......	From top, 5 feet 6 inches..................
6	" " "	Next 24 feet below sample 5...............
1	Franklin Co., Columbus......	From top, down 6 feet 6 inches—Taylor Bell quarry..............................
2	" " "	Next 8 feet below sample 1 — Taylor Bell quarry..............................
3	" " "	Next 38 feet below sample 2 — Taylor Bell quarry..............................
4	" " Morgan Station.	From top, down 13 feet..................
22	Lucas Co., White House......	From top, down 7 feet—Pray quarry........
23	" " " "	Next 7 feet below sample 22...............
9	Marion Co., Owens Station....	From top down 19 feet—Owens' quarry.....
8	" " " "	Next 10 feet 6 inches below sample 9—Owens' quarry..............................
7	" " " "	Next 3 feet 6 inches below sample 8—Owens' quarry..............................
17	Ottawa Co., Marblehead......	Two feet 6 inches below "Bottom Rock"....
18	" " "	1 foot below sample 17....................
19	" " "	3 feet below sample 18....................
14	Sandusky Co., near Bellevue..	From top, down 23 feet 9 inches—Bellevue Stone Co..............................
15	" " " " ..	Next 3 feet below sample 14—Bellevue Stone Co..................................
16	" " " " ..	Next 26 feet 6 inches below sample 15—Bellevue Stone Co.........................
10	Seneca Co., Bloomville.......	From top, down 3 feet 6 inches—France's quarry..............................
11	" " "	Next 16 feet below sample 10—France'squarry
12	" " "	Next 6 feet below sample 11 " "
25	Wood Co., Weston...........	From top, down 4 feet—Kline farm.........
24	" " "	13 feet section—Pew Quarry...............

Corniferous or Devonian Limestones. (Peppel.)

Constituents.					Total.	Remarks.	Serial number of samples.
Silica.	Alumina.	Ferric oxide.	Carbonate of calcium.	Carbonate of magnesium.			
11.86	1.58	trace	55.30	32.21	100.95	Under the shale. Delaware (?).	26
3.02	0.95	0.25	91.31	5.12	100.65	Gray, shelly stone.	5
10.36	2.71	0.05	69.80	17.21	100.13	Blue, well bedded building stone............	6
30.06	3.08	0.10	54.60	10.45	98.29	Shelly, flinty courses.	1
10.30	1.15	0.05	81.60	7.62	100.72	Includes "Bone bed."	2
2.30	0.70	trace	91.66	6.06	100.72	Massive courses.	3
1.54	0.48	trace	88.85	9.92	100.79	Eridophyllum layer,down	4
1.24	0.69	0.05	95.25	3.47	100.70	Delaware (?).	22
1.66	0.96	trace	74.52	23.50	100.64	"	23
12.50	2.05	0.25	64.00	20.47	99.27	Blue rock, building and crushing.............	9
2.32	0.90	trace	88.37	8.38	99.97	Cap rock for flux.	8
3.42	1.02	trace	70.15	26.21	100.80	Lime rock.	7
5.64	0.56	trace	58.30	36.35	100.85	Flinty, not used.	17
42.02	0.70	trace	36.10	21.58	100.40	Very flinty.	18
2.06	0.64	trace	59.10	39.04	100.84	Light color, even bedded.	19
5.24	0.96	trace	56.30	37.91	100.41	Correlated as probably the top of the Lucas limestone, but found in a Corniferous area.	14
8.72	1.27	0.15	56.10	34.59	100.83		15
6.32	2.31	0.05	63.15	27.97	99.80		16
2.96	0.41	0.15	89.55	7.46	100.53	Gray stone.	10
22.76	1.44	0.10	62.30	13.18	99.78	Hard, blue, flinty stone.	11
4.38	1.90	trace	74.05	20.30	100.63	Hard, blue, well-bedded stone.	12
3.16	0.68	trace	83.25	12.98	100.07	Shelly cap rock.	25
3.76	0.62	trace	56.15	40.22	100.75	Blue, bedded building stone.	24

Analyses of Limestones of this Formation,

Serial number of samples.	Location of sample.	Thickness and relative position of stratum represented by this sample.
a	Crawford Co., Spore	Average of 10 analyses, representing 24 feet of rock face
b	" " "	1 analysis, probably from lower courses
c	Defiance Co., Defiance	Bleininger, 1903, shale burnt for cement
d	Delaware Co., White Sulphur	Chemist not known
e	Erie Co., Kelley's Island	Cleveland Rolling Mill Co., 1884
f	" " " "	Lord, 1889, Calkin's quarry
g	" " " "	" " Kelley's quarry
h	" " " "	" " " "
i	" " " "	" " " "
j	" " " "	" " " "
k	Franklin Co., Columbus	" 1887, Average of 8 analyses
l	" " "	" " Stratum called "Smooth Rock"
m	" " "	" " Lillie's quarry
n	" " "	" " " "
o	" " "	Mees, ..., Smith and Price quarry
p	" " "	" .... " " " "
q	" " "	" ...., " " " "
r	Marion Co., Marion	Lord, top of Columbus formation, Evans' quarry
s	" " "	Lord, Middle and Lower Columbus formation, Evans' quarry
t	" " Owens Station	Lord, 1887, Owens quarry, top 3 feet
u	" " " "	" " " " next 3 feet
v	" " " "	" " " " " 3 feet
w	" " " "	" " " " " 2 feet 6 inches
x	" " " "	" " " " " 4 feet
y	" " " "	" " " " " 4 feet
z	" " " "	" " " " " 3 feet 6 inches
aa	" " " "	" " " " " 2 feet 6 inches
ab	Ottawa Co., Hartshorn	Wormley, 1870, Hartshorn's quarry
ac	" " "	Lord, 1887, Hartshorn's quarry, cap rock, 8 feet 6 inches
ad	" " "	Lord, 1887, Hartshorn's quarry, next 11 feet down
ae	" " "	Lord, 1887, Hartshorn's quarry, next 5 feet 6 inches down
af	" " "	Lord, 1887, Hartshorn's quarry, lowest 5 feet, just above Waterlime
ag	" " Marblehead	Lord, 1887, Roessling's quarry
ah	" " "	" " " "
ai	" " "	" " Kunz and Johnson's quarry
aj	" " "	" " " " " "
ak	" " "	" " Ohlemacher's quarry

Compiled From Various Sources

Constituents.					Total.	Remarks.	Serial number of samples.
Silica.	Alumina.	Ferric oxide.	Carbonate of calcium.	Carbonate of magnesium.			
1.87	0.37	....	87.81	9.50	99.55	Thin bedded, blue.	a
8.92	3.99	....	56.04	27.82	96.77	Thick beds, used for building.	b
23.34	8.70	1.60	38.34	23.24	95.22	Carbonaceous matter, high.	c
1.30	0.28	....	92.64	4.75	98.97	Used for lime	d
1.81	0.75	....	87.50	9.75	99.81	Flux stone.	e
1.60	0.40	....	71.17	26.82	99.99	Burnt for lime.	f
0.85	0.27	....	97.28	2.00	100.40	Blue cap rock; rejected.	g
1.49	0.15	....	87.10	10.96	99.70	Ordinary cap rock, flux.	h
1.05	0.20	....	89.16	9.48	99.89	Bedded stone, building purposes.	i
1.65	0.14	....	77.22	20.19	99.20	Burnt for lime.	j
4.25	0.26	....	94.19	1.29	99.99		k
5.80	1.30	....	87.25	5.26	99.61		l
4.90	0.09	....	89.60	4.41	100.00	From smooth rock, 8 feet up.	m
4.95	0.46	....	90.77	3.26	99.44	From smooth rock, 6 feet down.	n
1.41	2.18	....	93.28	2.69	99.56	From smooth rock, 6 feet down.	o
1.94	1.08	....	81.14	16.00	100.16	Building stone, still lower.	p
3.20	0.80	....	94.80	1.21	100.01	Selected sample of best stone.	q
3.50	0.50	....	79.01	16.85	99.86	Average 3 analyses flux stone.	r
1.60	0.24	....	66.02	33.10	100.96	Used for lime.	s
3.20	4.00	....	88.30	2.58	98.08	Flux stone.	t
4.60	1.25	....	80.40	13.80	100.05	" "	u
2.92	4.33	....	84.70	8.64	100.59	" "	v
1.35	6.01	....	92.00	0.56	99.92	" "	w
1.57	3.05	....	85.55	10.39	100.56	" "	x
1.92	1.85	....	74.00	21.46	99.23	" "	y
2.20	1.97	....	66.15	27.97	98.29	Limestone.	z
1.65	2.65	....	72.85	22.38	99.53	"	aa
2.70	3.30	....	65.80	27.95	99.75	Position in quarry unknown.	ab
1.00	0.37	....	89.20	9.64	100.21	Flux and pier stone.	ac
2.65	0.44	....	77.23	18.85	99.17	"Bottom" rock, used for lime.	ad
6.48	0.45	....	64.52	28.83	100.28	Flinty courses; not used.	ae
3.85	0.65	....	57.98	35.57	98.05	Not used.	af
1.50	0.22	....	84.51	13.31	99.54	Cap rock.	ag
1.63	0.90	....	69.61	27.43	99.57	Bottom rock.	ah
1.55	0.40	....	81.48	15.84	99.27	Cap rock.	ai
1.77	0.06	....	73.61	24.26	99.70	Bottom rock.	aj
1.51	0.33	....	89.08	8.34	99.26	Cap rock.	ak

A study of this table reveals the fact that the different formations and different portions of the same formation do not retain for any large area a closely consistent character. Still there is a general similarity, which may become much more clear when the exact positions of the samples are definitely known. Judging so far as we can from the data available we may say:

First: That the Delaware limestone is generally high in calcium carbonate, and low in magnesium carbonate; in its upper shelly layers, viz:

	Per cent. $CaCO_3$	Per cent. $MgCO_3$
Bloomville	89	7
Spore	87	9
Delaware	91	5

It is also increasingly magnesian as we go down towards its bottom, though it does not become dolomitic, viz:

	Per cent. $CaCO_3$	Per cent. $MgCO_3$
Bloomville	70	20
Spore	56	27
Owens Station	64	20
Delaware	69	17

Second: The cap rock or upper portion of the Columbus limestone, so widely used for furnace flux, seems fairly consistent whenever it is clearly identified. It is a fairly high-calcium stone, too high for the general taste when used as a lime, but not high enough for use as portland cement, viz:

	Per cent. $CaCO_3$	Per cent. $MgCO_3$
Kelley's Island	88	9
Marblehead	88	8
Owens Station	88	8
Columbus	81	7
Morgan Station	89	10

If error has been made in correlating the Bloomville and Spore quarries as the Delaware formation, they would also fit in well as the top of the Columbus, viz:

	Per cent. $CaCO_3$	Per cent. $MgCO_3$
Bloomville	89	7
Spore	87	9

Third: The "bottom rock" of the Marblehead quarries which is widely used for limestone, and which is really the middle stratum of the formation at that place, shows a strong increase in magnesia, though not descending to the dolomitic ratio, viz:

	Per cent. $CaCO_3$	Per cent. $MgCO_3$
Kelley's Island	77–75	25–20
Marblehead	77	18
Owens Station	70	26

At Columbus, however, the magnesia has decreased very markedly, for we find the cross section of the bottom forty feet of the quarry showing:

	Per cent. $CaCO_3$	Per cent. $MgCO_3$
Columbus	91	6

Whether this correlation of the Columbus section be accepted or not, the fact remains that the thickness of low-magnesia rocks has greatly increased there over any other locality of which we have record.

Fourth: The composition of the extreme bottom portion of the Columbus formation, which is usually not exposed and which is not worked even where exposed, unless at Bellevue, seems to be increasingly magnesian, though still not reaching the dolomite ratio. We have sure data but from one point, viz:

	Per cent. $CaCO_3$	Per cent. $MgCO_3$
Marblehead, 10 feet above bottom	64	28
" 5 feet, bottom stratum	57	35

If, however, we accept the Bellevue section as belonging to the Corniferous, in whole or in part, its composition fits in well with what we know of it at Marblehead, viz:

	Per cent. $CaCO_3$	Per cent. $MgCO_3$
Bellevue, top sample	.56	37
" middle sample	56	34
" bottom sample	63	27

It seems incredible that the whole fifty-five feet of the Bellevue section can belong to the bottom stratum of the Corniferous. But it is just as incredible that it can belong to the Lucas limestone, the most constant and unfailing dolomite in the state. The disturbed nature of the ground hėre has been mentioned. If it is merely glacial, as Winchell thought, it could not account for changes of composition. If it is an upheaval or crumpling of the strata as Mr. Peppel thought, there is no reason why this should produce any change in the ratio of the lime and magnesia. If it stands for disturbed conditions of deposition, it might very easily stand for change in composition, such as we find.

The two formations, the Columbus and Delaware, show parallel conditions, viz: *First:* A top layer, more or less shelly in nature, and more or less highly calciferous, with magnesia below ten, and often below eight per cent. *Second:* A lower layer, more magnesian than the upper, but never reaching dolomitic proportions, usually about twenty per cent.

The chemical evidence seems to indicate that in both the Columbus and the Delaware formations, the same influences were at work during deposition, and that these influences underwent the same progressive alteration from the beginning to the end of the period.

Uses. *Building Stone.* Both phases, the Columbus and the Delaware, yield building stone on a large scale. The upper portion of both is apt to be shelly and unfit, but the middle and lower beds are very good. The Delaware stone in particular has a reputation for this purpose. The large centers for building stone are at Columbus, Delaware, Owens Station, Marion, Marblehead and Kelley's Island.

Pier Stone. Along the lakes, where docks, piers, breakwaters, etc., are built, a low grade building stone is obtained from the cap rocks. The irregularity of the bedding and the small pieces into which it breaks are less objectionable than in other work, and once such a structure becomes filled with mud and silt in its interstices, it is as solid and enduring as is needed.

Ballast and Crushed Stone. There is a very large production of this sort from the Corniferous, first, because there are frequent flinty streaks which must be rejected for other purposes; second, the constantly increasing demand for crushed stone as a commodity. The large use of concrete in construction is one cause of this. Hence, the waste which goes to the limekiln in many quarries goes to the crusher in these cases. Also, the use of building material in this form is growing very rapidly, and in many cases quarries are crushing rock which could and would have been sold as building stone in previous years. Among the crushed rock plants operating on the Corniferous, those at Columbus rank among the largest in the United States. Their output runs up into several train loads per day. Bloomville, Spore, Marion, Owens Station, and Marblehead are also large producers of crushed stone, and Marblehead has a very large grinding plant for making limestone ready for glass manufacture.

Lime. Lime of hot, quick-slaking character is produced on a very large scale at Marblehead and Kelley's Island and to a less extent at Marion, Owens Station, White Sulphur and a number of other points. For years, lime was burnt at Columbus, but the industry is of little importance today. The lime produced from the bulk of the Columbus formation at Columbus is even hotter and quicker than the usual Corniferous lime and is at some disadvantage. Also the manufacture of mortar in Columbus and other cities is rapidly falling into the hands of large concerns who employ mechanical methods of slaking, mixing, aging and handling, and who naturally tend to purchase their lime from large dealers. This tends to discourage the production of lime in a small way by local kilns, and concentrates the trade in the hands of large plants who also employ advanced methods for cheapening their product.

Flux. The quarrying of limestone for fluxing iron ore in blast furnaces, and for the refining of steel in the basic open-hearth process, has become a large industry by itself. This trade is restricted largely to the Corniferous, in Ohio. The cap stone of the Columbus formation, carrying eighty-five to ninety per cent. carbonate of calcium, is the most approved horizon for this purpose, and little or none of the dolomite limestone of the Niagara or Monroe is used for this purpose. Even the seventy to seventy-five per cent. stone of the middle Columbus formation is not desired. Iron smelters prefer the presence of five to ten per cent. of magnesia, but do not want large amounts.

When selecting limestone for this purpose, another factor enters, i. e., the amount of phosphorus in the stone. Local limestones of great purity and containing ninety-four to ninety-six per cent. of carbonate of calcium are rejected at Ashland, Ky., and Ironton, Ohio, on account of the phosphorus, and Columbus stone is hauled down, a trip of one hundred to one hundred and ten miles, to replace it. The amount of phosphorus in the Corniferous is sometimes as low as 0.008 per cent. The "Bone-bed," a stratum some three to six inches in thickness, lying at the top of the formation or between the Columbus and Delaware formations, is crowded with fish teeth and bones, and samples of this stratum not infrequently contain several per cent. of phosphoric acid. The rigid exclusion of this stratum must be effected, if acceptable flux-stone is to be produced.

Cement. The two formations, in their average exposures, do not give any hope of forming the basis of a portland cement industry. The magnesia, which is the critical feature in this connection, is seldom below seven or eight per cent. and oftener about ten, in the beds which are nearest to the cement-making quality, while twenty to twenty-five per cent of magnesia is the rule elsewhere in the formation. In Columbus alone, of all the points studied on the horizon, are conditions more favorable.

But, at Columbus, while the latest evidence shows an abnormal thickening of the low magnesian beds, or a change in composition in beds which are elsewhere magnesian—in any case a thickness of thirty to forty feet of rock, averaging six per cent, or less,—and while numerous other samples lying at various positions in this formation have been taken, which show magnesia running down well within the approved portland cement ratios, the fact still remains that the locations seem of doubtful value for portland cement manufacture for the following reasons:

First: There is a stripping of fourteen or fifteen feet of rock, which would have to be removed to uncover the cement stone. A cement company could not, by itself, afford to handle so large an amount of expensive dead material. Neither could it profitably market so large a quantity of one quality of stone—and an inferior quality at that—without having other stone to sell also. In short, the cement stone could only be obtained at reasonable cost, if it was obtained from a large quarry, producing all kinds of stone and of which the cement stone would not be the largest single factor. This means that either one of the existing quarry companies or a new one of sufficient financial strength to force its wares into the market on a large scale would have to supply the cement material.

Second: The stone which shows six per cent. magnesium carbonate in thirty-eight feet of the bottom cross section is composed of some layers of much lower magnesia, and others much higher. This is proven by the quoted analyses by Professor Lord, k to g, Table V. This would mean therefore the acceptation of certain layers and the rejection of others in the forty feet of stone of average acceptability. This would mean extra expense in quarrying and, still more important, the constant danger of impure stone getting into the cement stone, through the ignorance and indifference of quarry employes. The problem of keeping the magnesia uniformly and properly low would therefore be more severe than in any of the plants which have established themselves on a firm basis elsewhere in the country. This would be the case whether the quarry were operated as an adjunct to the cement business, by the cement company, or operated by an outside company merely intent on selling the stone on favorable terms.

On the other hand, Columbus is well situated with reference to transportation facilities; it is accessible to coal of all sorts and qualities at low rates, as a vast coal traffic from southeastern Ohio, and West Virginia, passes through it; and lastly, while the difficulties and handicaps noted above are all real and important, they are by no means insuperable to a company which enters the business with a full appreciation of these difficulties and prepares to overcome them in the proper way. In short, the Corniferous of Columbus as a site for a portland cement industry is good enough to make success possible to a company managed with the highest grade of business and technical skill. With the kind of skill and experience which most newly organized companies bring to bear on their affairs, the outlook for success would be small.

THE MAXVILLE LIMESTONE.

This formation is the first break in the long series of clays, shales, sandstones and conglomerates which follow the last of the Devonian limestone beds. It is the precursor of a new type of limestones, very different from the heavy, solid beds of the earlier formations. The coal measure type, to which the Maxville belongs, is characteristically a thin stratum usually more highly colored than the older beds—blues, grays, buffs, even blacks are found, all of deeper tint than elsewhere. These thin bands, often only a foot or two, and very seldom exceeding ten feet, are of remarkable continuity. By them, chiefly, the stratigraphy of the coal measures has been worked out, for they are the most uniform and characteristic members of the formation. Coals are greatly subject to cut-outs, wants, faults, etc., but limestones, standing for a period of quiet marine invasion, generally are constant when everything else fluctuates.

The Maxville, however, being the first of this new type of limestone to form, is not a fair example of the type to which it belongs, in the fact that it is markedly discontinuous. It is apparently a basin deposit, formed here and there where the topography of the surface at that time caused lakes or lagoons to accumulate. These basins were probably not continuous, or in communication, with each other. At least, the deposits show wide differences in composition and stratification in short distances. An interesting fact is the occurrence, near Logan, of a conchoidal flint fireclay in basins, on apparently the same horizon as the Maxville stone. No point can be cited where the two are found together, but in one section the limestone is found at the top of the Logan formation, and overlain with the coal measure shales, and in another the fireclay is found occupying the same position with reference to the other strata. The conditions under which flint fireclay is formed are not well understood, but it is thought that at least the water in which it settled was very still and quiet, and possibly much covered with aquatic plants, whose life and decomposition was a potent factor in the purification of the clay to a degree beyond that of other clays of the same age. This basin structure agrees with the occurrence of the Maxville, but while one pond or lagoon might be fresh water and covered with plants, and accumulating pure clay, another not far distant might be salt or brackish water and collecting calcareous matter instead of clay.

The same bed changes rapidly in composition also. For instance, at Fultonham, Muskingum county, the formation at the center of the largest known basin is a very pure and valuable high-calcium stone, while on the edges of the same basin, near Mt. Perry and three miles north on Kent's run, the thickness has dwindled to one-third and the chemical character has been altogether readjusted, and the stratification also has changed. This is another point of similarity between the occurrence of the Maxville and of flint fireclays; in the Missouri clay-pockets the deposit usually forms a large, roughly conical mass, lying inverted with its apex downward and its base on the surface. The apex is supposed to represent the deepest point of the pool in which the clay was collected. The center and interior portions of this inverted conical mass of clay is fine and pure while the margins and bottom become progressively more impure and sandy as the original shoreline is approached.

The Maxville in Ohio is found above drainage level in but few localities. It is reported as regular and of great thickness in southeastern Ohio, where it is cut by the oil-driller in many holes, but it is cut off from present or prospective value by its depth under ground. The chief superficial deposit, and the only one where the formation has the least economic significance, is the field from which it takes its name, in Hocking, Perry, Muskingum and Licking counties. Its maximum extension is believed to be about thirty miles in length and from fifteen miles wide at its northern end down to four or six miles wide at its southern end. These limits would include an area of about two hundred square miles.

It is not believed, however, that the stone occupies more than a small part of this area. Deposits are actually known to exist in seven localities, of which four were accessible for sampling. On the other hand, the whole area has been industriously searched, and no other localities discovered. In the most of the territory, the formation should be under cover, but its outcrop does not appear at very many places where it is stratigraphically due.

The seven points above named are:

Green township, Hocking county, on the Culver Smith farm.

Between Winona and Webb Summit, on the Hocking Valley railroad.

Near Maxville, Monday Creek township, Perry county.

Reading township, Perry county, on the Poling farm.

Near Glenford, in Hopewell township, Perry county.

Near Brownsville and Gratiot, Bowling Green and Hopewell townships, Muskingum county.

The Fultonham area, beginning near Mt. Perry, Madison township, Perry county, and extending southeast to a mile beyond White Cottage and northward to the southern edge of Hopewell township, Muskingum county, on the land of John Stein.

Table No. VI.—Analyses of the Maxville Limestone

Serial number of samples.	Location of sample.	Description of sample.
0–51	Hocking Co., Green Tp.......	11 feet thickness exposed. Culver Smith farm.
	Muskingum Co., Fultonham...	12 feet, top of formation. Upper quarry....
0–61	" " White Cottage	9 feet, top of formation. Towards Fultonham
0–60	" " Kents Run...	15 feet, whole formation. John Stein's farm..
0–62	Perry Co., Madison Tp.	23 feet, whole formation. R. R. cut........
0–56	" " Reading Tp.,Sec. 25	10 feet 6 inches thick. Bottom of vein.......
0–57	" " " " " .	12 feet thick. Top of vein.................
0–53	" " Monday Creek Tp..	2 feet thick. Top of vein..................
0–52	" " " " " ..	2 feet 10 inches. Shale stratum............
0–55	" " " " " ..	4 inches. Limestone streak in shale........
0–51	" " " " " ..	5 feet. Buff stratum.......................
0–54	" " " " " ..	4 feet 6 inches. White "hardpan" ....

Analysis of the Maxville Limestone

a	Hocking Co., Winona	Top stratum of vein (N. W. Lord)..........
b	" " "	Bottom stratum " " " ....
c	Muskingum Co., White Cottage	J. H. Roberts' quarry (Wormley)..........
d	" " Maxville.....	D. Hendricks' farm (Lord)................
e	" " "	" " " " ....

This last area is the only one of much real promise. The others are generally magnesian, or thin. Description of each site can be consulted under the respective counties. The Fultonham area is about seven or eight miles in known length, by four miles in known breadth, making possibly fifteen or twenty square miles altogether, but its western and northern edges are known to be thin and magnesian, and the whole area known to be good is only some four miles long by one or two miles wide.

Physical Character.—The physical character is most varied. No type can be recognized. In some places, a conchoidal variety like flint or flint fireclay is found; at others, a soft, porous, light stone. The commonest phase is a white or light buff color, earthy or conchoidal fracture, little crystallization, and good weight. Blue beds occur, however. As a rule, the stone is not well bedded, but some phases are of proper thickness to work well.

Chemical Character.—A similar diversity exists here. There is no recognizable type. The following analyses are all that could be obtained:

Made for the Survey by S. V. Peppel.

Constituents.						Remarks.	Serial number of samples.
Silica.	Alumina.	Ferric oxide.	Carbonate of calcium.	Carbonate of magnesium	Total.		
8.16	2.42	2.80	77.45	9.40	100.23	Several feet not exposed.	0–50
2.80	1.16	....	92.80	2.13	98.89	R. W. Nauss, analyst.	Nauss
3.04	1.54	0.40	92.92	1.21	99.11		0–61
6.96	2.35	1.85	82.30	5.72	99.18	Sec. 15, Tp. 18, R. 1.	0–60
9.88	2.98	2.02	69.76	14.71	99.35	Section contains shales and iron ore also......	0–62
12.94	2.70	2.00	72.36	10.68	100.68	Blue, well bedded.......	0–56
3.80	0.94	2.70	82.33	8.46	98.25	Buff, shelly.	0–57
16.34	1.70	1.00	80.35	0.68	100.07	D. Hendricks' farm, S.17	0–53
43.86	17.87	2.01	31.15	4.31	99.20	" " " "	0–52
10.16	2.34	0.50	86.27	1.40	100.67	" " " "	0–55
9.56	1.54	6.20	54.70	27.15	99.15	" " " "	0–51
6.14	1.40	0.40	90.96	0.90	99.80	" " " "	0–54

Compiled from Various Sources.

5.45	5.60	....	56.30	32.40	99.75	Average of 3 analyses.	a
12.10	0.45	....	86.90	0.80	100.25		b
15.76	4.40	....	49.80	30.15	99.55		c
3.60	0.60	....	95.10	1.30	100.60	Bottom, gray stratum.	d
3.75	7.16	....	57.86	30.78	99.66	Top or buff stratum.	e

county, Ohio, are supplied from an opening in the Putnam Hill limestone; which is there eight feet in thickness. The following is the composition of the stone:

	Per cents.
Silica	4.12
Alumina	1.86
Ferric oxide	1.20
Carbonate calcium	91.16
Carbonate magnesium	1.63
Total	99.97

Localities where this stone is of suitable composition are not rare, but no other locality can be cited where the stone assumes a thickness at all sufficient for any extensive cement industry. It is usually a dense gray limestone, from two to four feet in thickness, which could not profitably be stripped or mined.

THE FERRIFEROUS LIMESTONE.

The Ferriferous limestone was named, not because it is itself more than usually high in iron, but because it is the key or landmark by which a considerable vein of iron ore is located. The ore in question is an impure limonite or hydrated oxide on the weathered outcrop, but under the hill soon turns into a hard blue carbonate or a gray oolitic carbonate of iron, with but little limonite among it. The limestone was thus early identified with the mining of ore, and also furnished lime for smelting the ore when won. Hence the name.

In stratigraphical position, the Ferriferous limestone belongs a short distance above the Putnam Hill limestone and from twenty to forty feet below the Lower Kittanning coal. This places it near the bottom of the Allegheny formation.

It occurs in two areas in Ohio. The northern, including Mahoning, Columbiana, Portage, Stark and Carroll counties, contains occasional patches of this stone. It is not the uniform and safe guide to stratigraphical position here, which it comes to be in the southern area. It is more of a basin deposit apparently, and though basins of considerable size may possibly be found, it has left comparatively little impression in this district, as a source of wealth. In only a few places is it well known; the most important of these is at Lowellville, Mahoning county, where it is the basis of a large industry for furnace flux and has been for many years past. Toward the southwest, the formation becomes more and more sparing in its exposures, and thinner, until in southwestern Stark county and northeastern Tuscarawas county it disappears, and the Putnam Hill limestone comes in on nearly the same horizon, but stratigraphically distinct.

The southern area, which is the important one, begins in Vinton county on the north, and runs south through Jackson, Gallia, Lawrence and Scioto counties, passing over into Kentucky. It is strictly a border or marginal deposit, occurring in a band about six or eight miles wide from its first exposures on the hill tops in the west, until it disappears under drainage level on the east. Undoubtedly it may be confidently expected in drill holes and shafts for a short distance east of its drainage level, but its presence under drainage level is not yet a matter of economic significance, as it probably could not now be worked at a profit from deep shafts.

The total area covered by the formation in the Ohio part of this southern deposit is probably about 400 square miles.

The thickness of the stone varies from four feet or less on the extreme western and northern outcrops to six as the average over the field as a whole, and eight or possibly even ten feet in limited portions of the central and southeastern part of the above area. Its roof material is iron ore, a few inches in thickness. This is usually overlain by fifteen to twenty feet of a soft yellow shale. This material makes easy stripping, but very difficult mining, as it is too weak to stand well as a roof, especially in view of the heavy blasting required to dislodge the limestone. Occasionally, the shale cuts out and is replaced by a heavy sandstone ledge. This makes stripping commercially impossible, and mining easy and safe. Hence, the nature of the overlying roof material profoundly influences the method of working; in fact, practically controls it.

For this reason, all areas of the Ferriferous limestone where the sand-rock roof is known to occur will be indicated, as these areas are the ones in which the largest plants could reasonably expect to get their stone supply with regularity. This question will be taken up in detail later on.

The areas where the formation is known to occur, with such facts as have been collected as to its thickness, the nature of its roof, and location for mining or stripping, are given in the succeeding lists:

LAWRENCE COUNTY.

The limestone is not found above drainage in the eastern townships of the county, including Rome, Union, Windsor, Mason, Fayette, Perry, Lawrence, Aid and Symmes. It is shortly below the surface of the valleys along the western edges of Perry and Lawrence townships, and may possibly be above drainage in very limited areas in northwestern Perry, and in sections 6 and 7 of Lawrence township. No limestone workings in these areas are known to the writer.

Upper Township.—*Section 31*—Good, rock-roof limestone; quarried for furnace flux, in California Hollow.

Section 30—Bottom land; little or no limestone.

Section 25—Good rock-roof limestone; quarried in California Hollow, on south side of Ice creek.

Section 26—Bottom land mostly; a patch of good stone occurs in the northwestern quarter.

Section 27—City of Ironton; bottom land.

Section 23—No limestone known to occur.

Section 22—A small area of rock-roof limestone on the Stewart tract, on the northern edge of the section.

Section 21—City of Ironton; cement plant located in this area, obtaining limestone from mine.

Section 20—Bottom lands; no limestone.

Section 13—No report.

Section 14—No rock-roof limestone known in this section.

Section 15—Probably some rock-roof stone occurs in the southern portion. Valley of Storm creek cuts out stone in the northern portion.

Section 16 and 17—No report.

Section 12—No report.

Section 11—Valleys do not cut down to level of limestone. Nothing known of its condition or thickness.

Section 10—No report.

Section 9—A want is encountered in this section. The Kittanning coal is present, but the limestone and iron ore are nowhere found.

Section 1—No report.

Section 2—Contains rock-roof limestone in the northern half.

Section 3—A fault or "want" cuts out the limestone in most of this township. Occurs only in occasional patches.

Section 4—Similar conditions to those of sections 3 and 9.

Section 5—No limestone.

Hamilton Township.—This is mostly lower-lying land, and in but a small area in sections 1, 2 and 3 is the limestone stratigraphically due. It is probably absent, however, as all the stone for the Hanging Rock furnace has been obtained at more distant points.

Elizabeth Township.—Range 18. *Section 36*—No report. Limestone probably under drainage.

Section 35—A good area of rock-roof stone in the township. The Kelley ore diggings have exposed the facts.

Section 34—No report.

Section 33—No report.

Section 32-31—There is only a little limestone in this area, and what occurs has a shale roof and can only be won by stripping.

Section 30—The limestone becomes more regular here, but has no sandstone roof.

Section 29—Same as 30.

Section 28—No report, probably like 30.

Section 27—The limestone in the northeast quarter of this section is good, with rock-roof.

Section 26—A good patch of rock-roof stone in the northwest corner. Otherwise, the stone has shale roof or is wanting.

Section 25—No report; probably under cover.

Section 24—No report; probably under cover.

Section 23—No rock-roof stone.

Section 22—A small area in the southeast quarter, not extending as far as Etna furnace.

Section 21—No rock-roof stone.

Section 20—One small patch of rock-roof stone. The stone is everywhere constant and good, but roof is mostly shale.

Section 19—No report.

Section 18—No report

Section 17—No report.

Section 16—The limestone occurs along Cannons creek, with good rock-roof throughout.

Section 15—A fine body of rock-roof stone.

Section 14—A fine body of stone, but goes under drainage at the north line of the section.

Section 13—No report; under drainage level.

Section 12—Mostly under drainage level.

Section 11—Has a good rock-roof wherever the limestone is above drainage.

Section 10—Fine body of rock-roof stone.

Section 9—Fine body of rock-roof stone.

Section 8 and 7—No report. Stone is present, but character of roof not known.

Section 6—No report.

Section 5—Fine rock-roof limestone. Burke's mine located in this section is a most successful and well-managed one.

Section 4—Fine rock-roof, except where valley cuts out the limestone altogether.

Section 3—A small body of rock-roof stone in the southeast quarter. Valley cuts out limestone in most of this area.

Section 2—Only a little rock-roof stone in the southwest quarter. The roof on the balance is a weak shale.

Section 1—No report; mostly under drainage.

Elizabeth Township.—Range 19. *Sections 21–22*—Very little limestone, in scattered areas. Shale roof only.

Sections 18–17—No report.

Sections 16-10-9-1—The limestone formation is well above drainage in this territory, and is undoubtedly present to some extent. Usually more steady to the northwards.

Sections 15-11-8-2—This ground is largely cut out by the valley of Pine creek. Limestone areas are near the hill tops, and cannot be large.

Sections 13-12-7-3—Limestone confined to hill tops and cannot be important in area.

Decatur Township.—*Section 36*—Under cover entirely.

Section 35—Under cover almost everywhere. Shale roof, when visible.

Sections 34-33-32-26-27-28-23-22—Comprising the Mount Vernon furnace property, is said to show the shale-roof exclusively. The stone is generally present.'

Sections 30-31-20-19—No report.

Sections 25-24-1—Limestone under drainage.

Sections 13-14-15-16-17-18-7-8-9-10-11-2-3-4-5-6, and Range 18 of Bloom township of Scioto coun.y, are all good limestone territory. The rock-roof is largely absent, but the coal under the limestone comes in as a counter advantage. The coal is very thick, six feet occasionally, in the vicinity of Olive furnace. The limestone is generally above drainage in this area, and is getting near the hill tops in the western side. In section 7, the limestone has a thickness of eight feet, with sixty-two inches of coal underneath. This stone lies here about one hundred feet below the hill top and therefore has considerable area. The roof is shale.

Washington Township.—*Section 36*—The limestone lies very low in the valley and in most of the township is not accessible to drift-mining operations.

Section 35—Contains a good body of stone, which may be reached above the drainage level along the deeper valleys.

Section 34—The stone is well above drainage in this township, and is from six to eight feet thick, with coal of good thickness underneath. Both have been worked. The limestone is covered with shale; no rock-roof is reported here, unless on the northern edge of the township.

Section 33—The stone is above drainage in this section. No workings of importance were seen. The easily accessible points to get limestone near to Olive furnace have resulted in small diggings in both sections 33 and 34.

Section 25—Limestone under cover, and said to be wanting.

Section 26—No report.

Section 27-28-22-21 and Section 20, Range 18, Bloom township, Scioto county adjoining. This area is largely covered with a fine bed of rock-roof limestone. There is about 2,000 acres in this tract. The ore diggings of Bloom furnace were largely in this area. The rock-roof was as great a drawback to them as it promises to be an advantage to the future users of limestone in this vicinity. The old ore diggers used to make their excavations on the sandstone above the ore, rather than in the hard limestone beneath the ore, as it was easier to work. They used the lowest excavations in which men could work, literally crawling into the openings, except on the entries or hauling routes.

Section 23—Limestone present, but without the rock-roof. Coal has been opened under the limestone at several points.

Section 24-13—Limestone deeply covered if present at all. Said to be wanting in this area.

Section 14—Limestone deeply covered in most of area. No rock-roof reported.

Sections 15-16—Limestone in good situation for working. No data as to thickness or roof.

Sections 1-2-3-4-9-10-11—All well situated for working the limestone, which is here approaching the upper parts of the hills. The stone has been worked in section 2, around an old blast-furnace, for flux. The roof is shale.

Section 12—The stone lies rather deeper here, and is not far above drainage in the valleys.

SCIOTO COUNTY.

Scioto county lies on the extreme western edge of the limestone area. At two points, workings have been made—at Howard furnace, section 12, Vernon township, and at Eifort Station, section 5, Range 18, Bloom township. The Howard workings are not known to be Ferriferous, and are probably Mercer in age. The Eifort quarry is typical of the Ferriferous, and is an important place as offering an illustration of what may be done with this formation in the large areas of hill-top occurrences where the roof is composed of weak, weathered shales.

It is certain that hill-top areas of limestone will be found in the two eastern tiers of sections of Bloom township, and the two eastern tiers of sections of Vernon township, though there is less of it towards the southern portion of the area indicated. The Eifort quarry shows the following section:

		Feet.	Inches.
1.	Hill-top. Decomposed shale soil	25	0
2.	Lower Kittanning coal, not open	3	0 (?)
3.	Fire clay, light colored	8	0
4.	Buff shale, with iron ore kidneys	25	0
5.	Iron ore	0	6
6.	Ferriferous limestone	7–10	0
7.	"Draw Slate"	0	3
8.	Clarion coal, with two partings	3 to 4	0
9.	Fire clay, light colored	4 to 6	0

The products of the works include coal, iron ore, limestone, shale, and fireclay. In fact, every mineral stratum opened is marketed in greater or less degree.

GALLIA COUNTY.

The Ferriferous limestone lies below drainage level in this county in all except Greenfield, the extreme western township, and possibly the extreme western edges of Raccoon and Huntington. In Greenfield township, the stone appears above the valley level only in sections 21, 16, 15, 10, 11, 9, 8, 7, 17 and 18. The stone is reported as wanting from about section 21 to section 36 Washington township, of Lawrence county, a distance of 5 or 6 miles. The best limestone territory in the county is undoubtedly opened in the northwestern sections.

There is a quarry opened by Mr. Isaac Hall at Gallia funace under the name of the Gallia Lime Company. The stone here measures six to seven feet in thickness and is of good quality. The quarry is not in operation. Seven thousand tons were taken out in 1900, and this was used chiefly as a furnace flux. The roof is of shale. This quarry is only about twenty feet above the valley of the head waters of Symmes creek at Gallia furnace. North, between Gallia and Kitchen Station, of Jackson county, the limestone is said to be wanting, but it probably merely happens not to outcrop, and would be found if looked for.

JACKSON COUNTY.

The Ferriferous limestone is found in the townships of Jefferson, Madison, Bloomfield, Franklin, Lick and Milton, all of which are in the eastern half of the county.

Jefferson Township.—The limestone occurs in sections 36, 35, 34, 33, 32, 31, 25, 26, 27, 28, 29, 24, 23, 22, 21, 13, 14, 12, 11 and 1. In all of this territory it is in isolated hill-top areas, which become smaller and more worthless as we progress to the northwest. The heaviest stone-roof area is probably that in the vicinity of Washington furnace in section 36. No quarries of importance are located in this township. The roof is generally shale, so far as is known, and being close to the top of the hills, it is too weak to stand undermining.

Franklin Township.—The limestone maintains the same character here as in Jefferson township, viz., hill-top areas of small size and not favorably situated for mining. Much stone could be secured by stripping, around the outcrop, but this kind of winning makes a precarious supply, and in bad weather, dirty, clayey stone as well. The following sections are the ones in which to expect the stone to be present: Nos. 36, 35, 25, 26, 24, 13, 12, 1 and 2.

Lick Township.—The same facts as above apply also to sections 36, 35, 25 and 24 of Lick township.

Madison Township.—Practically the entire area of Madison township is limestone territory. The seam lies fairly well towards the top of the hills along the western tier of the sections, but as the hills generally show a little No. 6 coal on the top, the area of limestone must amount to substantially one-third of the whole surface. In the second tier of townships, viz., 5, 32, 29, 20, 17, 8 and 5 (north) there is some limestone, though the railroad cutting through here from north to south follows a depression or wide valley in which the stone is cut out. In the townships east of this tier, practically all of the territory is limestone country, as the valleys do not cut out large areas of it. In fact, the valleys are probably well above it, on the southeastern and eastern tier.

The stone is opened at Kitchen Station, section 32, where it presents a silicious phase six to seven feet thick. Its cover is soft shale of a yellow color. It is stripped only; the shale roof would not permit economic mining.

Bloomfield Township.—The situation in this township is about the same as in Madison township, just below it. The southeastern corner is well under cover, but the valleys of Raccoon creek on the eastern edge of the township and Dicksons run in the center and west, cut down below the level of the limestone, and thus render it accessible to mining operations. It is opened in section 32 in Limestone furnace, where it measures six feet. At this point, it is fairly near the hill tops and the area is not large. The roof is uniformly shale in this section.

Milton Township.—Milton township is largely covered with the limestone formation over most of its area. In section 8, near Wellston, and at Berlin Cross Roads, the formation is near the hill tops and of little commercial importance. A quarry was put in in section 23, a mile or so southeast of Berlin, a few years ago, but the stone was won by stripping and benching, there being insufficient cover for mining. On the other side of the township, the limestone is still above drainage, though close to the valley level, in section 36 (south), 13, and 36 (north)·

In section 36 (south) near Buckeye furnace, the stone is thinner, four to six feet, and not promising. In section 13, the lime was six to eight feet thick, with considerable chert bands. In section 24, the Riverton mines, now abandoned, worked the Clarion coal under the limestone stratum. The stone was not seen.

In section 36 (north) at Cornelia furnace, the limestone is eight feet thick and fairly free from flint. It is being quarried largely for cement manufacture. There are places in the quarry, however, which have been abandoned on account of the flint. ·The works are all strippings, though ample cover for mining exists. The roof strata are shale. In section 36, a mile further east, the limestone is beneath the valley level and is cut, eight feet thick, in the shaft of the Hanging Rock coal mine. Twenty-four to twenty-eight inches of draw slate separate the coal from the limestone. The cover material at this point is a streaked shaly sandstone, about twenty feet thick.

There is no doubt but the area of available stone in this township is large.

VINTON COUNTY.

The limestone is found in Wilkesville, Vinton, Clinton, Madison and Elk townships.

Wilkesville Township.—The formation is under deep cover at all points in this township except along the deep valley of Raccoon creek. It crops out at various points along this valley, and the underlying coal is mined at Minerton and Hawks Station. The limestone at those points is not very regular, it is from four to six and one half feet at Minerton, but is often cut out entirely. At Keck's mine, Hawks Station, the roof is largely sandstone, the limestone having failed locally. It is said that the stone shows up well near by, but it does not at the mouth of the mine, nor in the nearby railroad cuts.

Vinton Township.—The situation in Vinton township is about the same as in Wilkesville township. The valley of Raccoon creek cuts deep enough to expose the limestone as does the small branch running up past Oreton. The formation is mainly below drainage, and nothing is known of its extent or character. At Oreton, section 34, the limestone forms the roof of the coal mines. It is thinner and less valuable than at the Hanging Rock mine, due south two miles, and the sandstone has here been increased in prominence. This location has been seriously considered by experienced cement makers as the site for a plant, chiefly on the prospects of being able to extract all the stone, owing to its heavy sandstone cover.

Clinton Township.—The formation is present in the southeastern portion of this township. The nature or thickness of the deposit is not known.

Madison Township.—The formation is present in western Madison township. At Zaleski, it formed the roof of the mines which were worked there some years ago. In general, it may be said, of the limestone in Madison and Elk townships, and the few outlying points north of these, where the stone had been found, that the stone is thinner and oftener cut out or wanting and that this northern extension of the field has little prospects of being an important asset to its owners.

THE WINNING OF THE FERRIFEROUS LIMESTONE AND ITS ECONOMIC VALUE.

There are two well-defined methods of winning this formation, benching and mining.

Benching.—Benching or stripping is limited to the outcrops, removing the superincumbent earth and shale with plow and scraper, or wheelbarrow and shovel, followed by the quarrying of the stone by blasting. The iron ore which lies immediately on the stone and the coal which lies under it can be sold also, and helps to defray the cost of stripping. This method has some advantages.

First: All of the stone is available, when once the covering is removed. If any part of it must be rejected, it is from defects of composition and not from the exigencies of quarrying.

Second: The work of stripping is in the open air, and in good weather a man's time is more efficiently employed in the open air and sunlight, than in a mine.

Third: The drilling and blasting of the stone is of the easiest, where it can be approached from above.

It will occur to anyone, that as one goes in on the outcrop of a horizontal formation on a hillside, that the stripping will become heavier and heavier, as the hill rises.

Thus at the line A-B in the accompanying sketch, the depth of the stripping at the face of the cut is indicated at 15 feet, while by going back 10 feet further into the hill to the line C-D the yield of limestone will be increased by a prism of 80 square feet cross section, while the stripping will be increased by a prism of earth 50 square feet in cross section in addition to that which had to be removed previously.

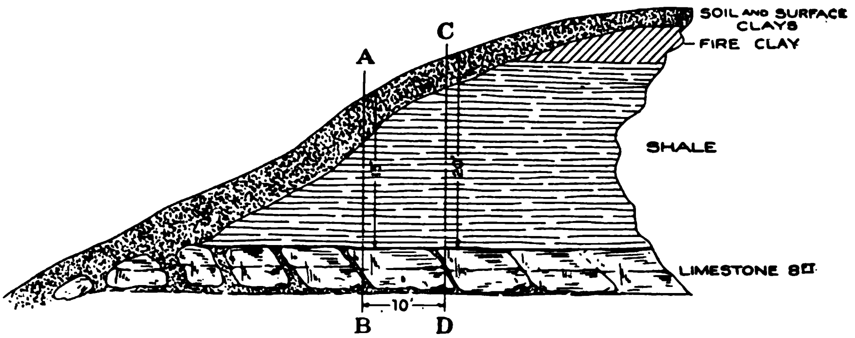

Figure 4.—Showing ideal structure of hill, and conditions governing the bench winning of limestone.

It is evident therefore, that there is an easily reached limit to the depth to which stripping can be profitably carried. Just what the limit is will depend: *First:* The thickness of the mineral stratum sought. *Second:* Its value per ton. *Third:* The nature of the superincumbent earth or stone to be removed. *Fourth:* The distance to which the waste earth must be carried before dumping. *Fifth:* Method of digging employed, whether by pick and shovel, plow and scraper, steam shovel or hydraulic stripping. The following conditions are typical of the limestone district of Lawrence and Jackson counties:

First: Thickness of limestone stratum, 8 feet 0 inches.

Second: Value per ton, $0.40.

Third Superincumbent earth. Shale, generally soft and weathered.

Fourth: Dumping ground. Immediately adjacent and down hill.

Fifth: Pick and shovel and wheelbarrow excavation.

Sixth: Iron ore, six inches thick, worth in the raw state about $1.00 per ton, is obtained.

Seventh: Coal three feet to three feet and six inches thick immediately underlies the limestone, and can be removed with the minimum trouble when the stone is gone.

Operating under these conditions, the customary depth to which a stripping is carried before being abandoned as unprofitable is from fifteen to twenty feet. It must be understood that where the maximum cut is fifteen feet, the average or mean cut is only one-half this amount, or 7.5 feet, as the excavation is a right triangle in section, whose area is one-half of the parallelogram composed by its base and altitude.

Without doubt, by use of hydraulic methods where abundant water supply is available, or by steam shovel where enough water cannot be obtained, a very considerably increased depth of cut could be obtained. The advantage from the use of better methods of excavation would probably come from the larger yield of stone in a given tract, rather than in lowering the cost of excavation per ton, for the temptation to cut deeper into the hillside and thus turn out a larger yield from the same working face would be well-nigh irresistible. Inasmuch as the stripping or benching method is based upon the idea of following the margin of the hills at the level at which the stone outcrops, and makes no serious effort to attack the great body of the stone, which is too deeply covered to be accessible except by mining, it follows that this method is a wasteful or extravagant one, and that to secure a steady and large supply involves workings extended over long stretches of hillside. This means the necessity of large real estate holdings, for the benching of limestone cuts up a country very rapidly, and renders it less valuable for other purposes. It also means heavy transportation costs, for after the stone is quarried it must be hauled back from the workings to the railroad or assembling point. All these considerations indicate that reduction of the cost of excavation per cubic yard would not probably reduce the cost of stone per ton, except indirectly, by reducing transportation costs and increasing the yield per acre, and thus reducing the value of the real estate ruined, which should be assessed as a part of the cost of the output.

In some localities, stripping of a maximum depth of twenty-five feet has been made by hand method, to win an eight-foot stone stratum which only sells at forty cents per ton on the railroad car. It is difficult to see how this would be done without loss.

Besides these considerations, there are some others which react unfavorably on this method of winning.

First: The unavoidable fluctuation in the quantity of the output owing to the interruptions of bad weather. It is practically impossible to win stone in open cut workings in snowy or muddy weather, and, in fact, it can only be done at a profit when the weather is at its best.

Second: The constant tendency to spoil the stone by allowing it to come in contact with wet, sticky clay and mud. This increases the silica a little, *but the alumina more in proportion*, and hence tends to make the stone less suited for portland cement mixing.

Mining.—The method of winning the stone by underground mining is much preferable to stripping and benching in most of the territory covered by the Ferriferous limestone. In the first place, it systematically undertakes to exhaust a given area as it goes. It does not obtain all the stone in the territory worked over—far from it. It would be considered good mining, if it brought out two-thirds of the stratum, leaving one-third in the hill for room and entry-pillars. But, even at this fixed rate of loss, it progressively works out the stone acre by acre. It yields a large output from a relatively small acreage, and does not necessarily depreciate the surface value of the land, or make it unfit for other uses.

Second: It affords a large output daily with little or no regard to weather. All of the hauling is in underground galleries, protected from rain or snow and usually in tram cars, instead of wagons.

Third: The stone can be kept cleaner than outside, as the roof and floor materials are seldom actually muddy and often dry and dusty. This is liable to make a difference of a per cent. or two of alumina in the cement, an item of no small importance.

On the other hand, the lowest price at which mining can be done is higher than that at which many thousands of tons can be obtained in bench strippings. The price at which the stone generally sells is such that mining is possible with a small margin for profit, while stripping can be carried back till the cut is about twenty feet deep.

The two processes, however, are not necessarily antagonistic. The mines cannot work cheaply or safely close to the outcrop. The roof strata usually are weak or rotten close to the outcrop, and make it expensive to support them, and dangerous as well, while underneath a good cover of fifty feet or more the rocks are hard and unaffected by water and air, and stand up well. The stripping on the other hand cannot work except where the stone is covered with but a shallow layer. Both methods may be applied to the same tract of land, and the total yield much increased thereby.

The Morgan and Horton quarry at Eifort, Scioto county, offers an excellent illustration of the simultaneous use of the two processes. Open cuts or benches have girdled the hills for a length of a mile or more, while one or more entries have been driven in at favorable points to win the stone lying too deep to strip. This firm has had an excellent opportunity to judge of the relative cost of the two methods. The comparison is made, however, between hand quarrying methods outside, with steam drills inside.

They find that where the earth to be removed exceeds ten feet, it pays better to mine an eight foot stone stratum, even where they leave a considerable part of the stone to support a very weak, treacherous roof. A former owner had girdled the hills with open cuts twenty feet or even twenty-five feet in depth, but Messrs. Morgan and Horton condemn this as entirely beyond the profitable limit, and state that mining is able to save money over stripping under these conditions. The mining operations at this point are interesting as pointing out the method which will apply to a very considerable part of the Ferriferous limestone areas. The roof is a soft yellow shale, which is strong enough for cover if it is deep in the hill and entirely unaffected by weather, but in points where the hill only rises fifty feet or so above the limestone, the shale makes a weak and treacherous roof. At Eifort, they dare not trust it at all, and accordingly, in the area covered by each room or entry, they mine out above seventy to seventy-five per cent. of the bottom part of the stone, leaving twenty-five to thirty per cent. of the upper part standing for a roof. The strong, dense limestone two feet or thirty inches thick makes a trustworthy support, and rooms can be worked without using scarcely a post, while if the limestone were all blasted down, the weak shale, still further weakened by the blasting, would require abundant and expensive mine timbers.

The stone happens at this point to be somewhat laminated, which makes it easy to break down the lower part, while leaving the upper stratum, but this condition does not generally hold good. The loss of the upper stratum in the rooms also reduces the yield of the stone per acre, to just about fifty per cent. of the total contents of the vein. Even under these conditions, the stone can be produced in large amounts at forty cents per ton on the car at a profit.

The method of working is shown in the following cut. First the coal is mined out for six feet back of the face of the limestone. This coal is not of high quality, but is easily marketable. In fact, it is mined in numerous places where the limestone is not taken down at all. When the coal is removed, the limestone is drilled by steam drills and blasted.

The under cut allows it to blast down easily. The stone is then sledged to sizes which can be lifted by men, loaded and sent out. A small locomotive does the outside hauling and mules gather the cars inside. The coal and limestone are loaded at the same hoppers, through parallel chutes, into railroad cars.

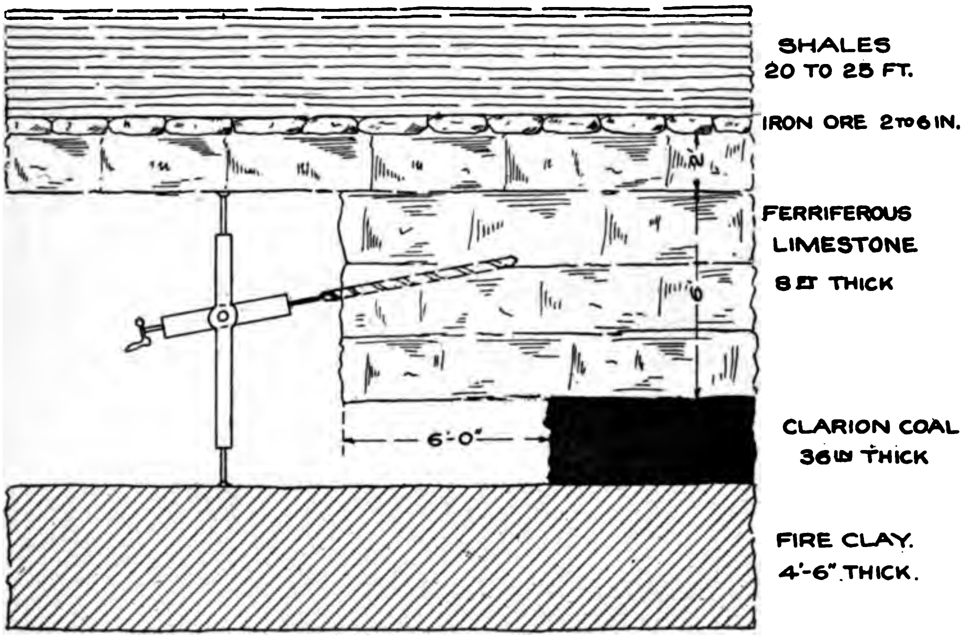

Figure 5.—Showing sections of Ferriferous limestone at Eifort, Scioto county, and method of working.

The nature of the roof is thus seen to be a matter of the very greatest importance. In areas where the shale is replaced by a heavy sandstone ledge, the full thickness of the limestone is blasted down fearlessly, increasing the yield from fifty per cent. up to sixty-six or seventy per cent. of the formation. Further, the rooms may be widened somewhat or the pillars decreased, so that the percentage may be still further increased to seventy or seventy-five. The following section was obtained at Burke's mine, Steece P. O., Lawrence county.

The following facts were obtained as to the conditions of mining at this point. The rooms are driven fifty to fifty-five feet wide, without posts. The shale and the little coal streak are "bunkered" out from under the stone to a depth of six or even eight feet. This is done primarily by blasting, but the miner has considerable picking to do to get the excavation cleaned out well. Three men are employed at this work alone. Black powder is used. The shale and dirty coal is thrown back in windrows on either side of the center track in each room, making mounds two to four feet high. It is kept carefully away from the pillars on either side so as to avoid rehandling, in case it may be decided to try to draw some pillars, when the mine is worked out further.

The stone, being under cut, is now ready to be drilled and shot. Five or six holes are made across the face of the room. These holes are put in by hand drill and sledge at a cost of twenty cents per foot. Six men are employed at this part of the work constantly. The holes start about the center of the vein and go upwards until at a depth of six feet they are within eighteen to twenty-four inches of the top of the vein. Dynamite is used for the stone. The total cost of explosives, caps, fuses, etc., amounts to about $125.00 per month. One row of holes brings down about one hundred and fifty tons of stone, which is then sledged and loaded into iron cars. Eight men handle all of the stone. Two men haul it from the mine to the tipple and dump it.

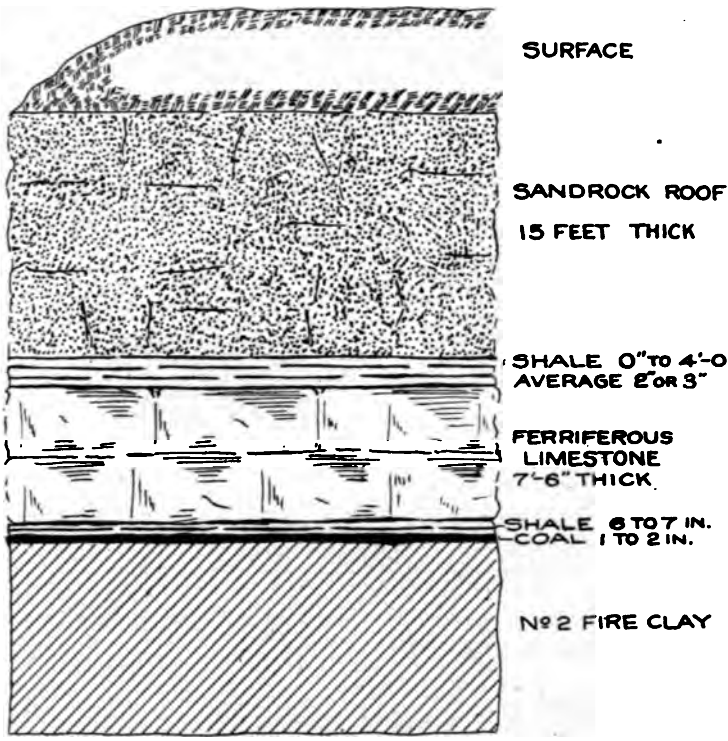

Figure 6.—Showing section of Ferriferous limestone at Burke's mine, at Steece P. O., Lawrence county, Ohio.

The thin and fluctuating vein of shale lying between the stone and sand rock is of great importance to the contractor, because the top he limestone often hangs and has to be shot again. The shot can be made in this shale at one-quarter the cost required to make it in the limestone. Also, it prevents any shattering of the sand-rock. The men employed here were as follows:

6 men drilling and blasting limestone.
3 men drilling and blasting coal.
8 men sledging and loading.
1 blacksmith.
2 haulers.
2 boys.
1 or 2 extra hands, repairing track, ditching, etc.
2 bosses or foremen.

—

25 men.

The output averages 2,500 tons per month, or 100 tons per man per month. The price paid for the stone was thirty-eight cents per ton. A little calculation shows that this labor cost is excessive and that at that price the wages per day would be small. Explosives alone cost $125.00 per month and the cost of mules, feed, track repairs, cars, etc. would make the profit very small. On the other hand, the use of steam drills would cut down the cost of the heaviest item by two-thirds. The contractor who was in charge of this plant gave as his opinion that, with similar roof and floor conditions to his own, using steam or air drills, the stone would be produced at a cost of thirty cents per ton, by working on a larger scale than his own.

These two mines at Eifort and Steece show both sides of the problem —the one with coal and a shale roof; the other without coal, and a sandstone roof. The cost of stone is not far apart as at present managed, but it could be made lower under the latter conditions than it could under the former. The coal underneath the limestone is not such a great advantage as it appears at first sight, if it must be mined and marketed just as fast as the stone is needed. This makes it a by-product proposition, which is always a troublesome thing. If a cement plant could use the coal itself, it would enormously simplify the problem, but the Clarion coal is sulphury and could not be so used, in the opinion of most cement makers. This is not yet wholly proven, but it is well known that sulphur would be a severe detriment.

If the coal were worked out ahead of the stone, the latter could follow along behind at will, but this would involve several undesirable features. The coal pillars would be apt to soften and squeeze when the stone was blasted, especially if they had been standing a long time since the coal was mined. Also, the timbers required are very long and, hence, expensive, so that the presence or absence of the coal is by no means essential to successful mining. In summing up the observations on the mining, the following general opinions were reached:

First: That a 6-foot stratum, with a sandstone or other hard roof rock, is as thin a vein as can be profitably worked.

Second: That an 8-foot stratum with a shale or other weak roof can be mined by leaving up a part of limestone to act as a roof material.

Third: That the cost of mining under either condition will not fall below thirty cents a ton even when worked with the best engineering methods, power drills, good transportation facilities, etc.

Fourth: That benching should be considered as a method auxiliary to mining, and not as an alternative. The two methods must both be used, to win the stone from any given tract as completely as possible.

Fifth: That the depth limit of benching is set by the cost of successful mining.

Yield Per Acre.—The stone may safely be taken at six feet per acre over the whole area in which it occurs. It was found less in but few places, and more in many exposures. Assuming the weight of the stone at one hundred and sixty pounds per cubic foot, which it should exceed, then the weight of stone per acre would be,

$$\frac{43560 \text{ sq. ft} \times 6 \text{ ft. deep} \times 160 \text{ lbs. per cubic foot}}{2000} = 20908 \text{ tons.}$$

In mining, even with the best of roof, the probability of the recovery of any ribs or entry stumps is small, and it is not likely that more than two-thirds would be taken out, which would be about 14,000 tons per acre.

Land containing favorable exposures of this stone could be secured at from $75.00 to $200.00 per acre. Assuming $100.00 as the average cost of land, then $100.00 ÷ 14,000 tons = 0.7 cents per ton, land value. Royalty varies from 2.5 cents to 5.0 cents per ton.

Rate of Exhaustion by a Cement Plant.—Analyses of the stone show that it averages about 90 per cent. calcium carbonate. On calcination, this would give,

$90 \times .44 = 39.6$ carbon dioxide or 1208 lbs. residue per ton. Of this, allow 200 lbs. for silica, alumina, iron, magnesia, leaving 1,008 lbs. calcium oxide. A good portland cement contains about 64 per cent. of calcium oxide. Hence,

$$\frac{1008 \times 100}{64} = 1575 = \text{weight of cement produced by 2000 lbs.}$$

limestone.

$1575 \div 390 = 4.0$ barrels per ton.

The output of a rotary cement kiln may be taken at 125 barrels per day. Four rotaries make a small plant.

$$125 \times 4 = 500 \text{ barrels per day.} \quad \frac{500}{4.0} = 125 \text{ tons of stone daily.}$$

$$\frac{14{,}000 \text{ tons per acre}}{125 \text{ tons per day}} = 112 \text{ days' work, or } 300 \div 112 = 2.67 \text{ acres}$$
per year.

These figures are only approximate, but indicate in a general way what would occur if a 500 barrel plant were to be established on a 6 foot vein of this limestone. Of course, every additional foot in thickness helps wonderfully on the yield per acre. From what has been said, it is clear that in the Ferriferous limestone area of southern Ohio, an asset of some present and great prospective value is found.

THE LOWER KITTANNING.

There is no constant or well marked horizon of limestone of which sufficient quantity is found to be commercially interesting, for several hundred feet above the Ferriferous horizon. Several formations swell up locally and offer for a limited area a possible source of supply for a cement industry. Of such a character is the stone at Lisbon, Columbiana county, where it has been used as the basis of a "Natural cement" industry for years past. It is only thirty-four inches thick, occurring on the horizon of the Lower Kittanning coal. It analyzes as follows:

	Per cents.
Silica	17.76
Alumina	7.94
Ferric oxide	1.86
Carbonate of calcium	66.25
Carbonate of magnesium	2.82
Total	96.63

The stone is won by mining.

THE MIDDLE KITTANNING LIMESTONE.

A similar stone at Rodgers, in Columbiana county, having a thickness of four feet six inches, has the following composition. It is obtained just under the Middle Kittanning coal.

	Per cents.
Silica	25.44
Alumina	10.62
Ferric oxide	2.34
Carbonate of calcium	55.59
Carbonate of magnesium	2.14
Total	96.13

The stone is won by mining, if at all. So far as is known, however, it has received no commercial development.

THE LIMESTONES OF THE MONONGAHELA FORMATION.

Between the great limestone formations of early geological time, ending in the early Devonian, and the formation of the Pittsburg coal in the Carboniferous, a vast time interval occurred during which no important return to calciferous conditions took place, in Ohio. The seas were building shales, sandstones, and conglomerates; strata of this sort of enormous thickness and area were laid down, but the periods when limestones were deposited were short, infrequent, and unproductive of important results, from the broad economic standpoint.

At the beginning, or a little before the beginning of the Monongahela period, the situation changed and limestones began once more to form an important if not predominant part of the strata deposited. These conditions maintained for a comparatively short period, geologically considered, yet long enough to leave a band of strata two hundred feet or more in thickness through which limestones are a notable ingredient. The lowest member of this group occurs just under the Pittsburg coal, and so on, with scarcely any intermission, every part of this stratigraphical space between the Pittsburg coal and a point fifty to sixty feet above the Meigs Creek coal is somewhere occupied by limestone strata. These strata differ markedly, however, from the western limestone beds, which generally are of great extent and considerable uniformity, chemically and physically. The Monongahela formations are basin deposits of no great area and manifesting no close agreement in composition, even between adjoining basins of the same age. Thus, while we have in this two hundred feet of strata, an immense stock of calcareous matter, which will sooner or later become of economic importance, we do not have beds of which many general statements can be made as to physical and chemical qualities.

For convenience in describing these formations they will be classed as the Pittsburg limestones and the Meigs Creek limestones. By the term Pittsburg limestone in this report is included all limestone strata from a point twenty feet below the Pittsburg coal to the Meigs Creek coal, a vertical range varying from one hundred and five to one hundred and twenty-five feet. By the Meigs Creek limestone is meant all limestone beds from the Meigs Creek coal to a point sixty feet above it.

Concerning the origin or conditions of formation of these limestones, and considering the areas covered by both the Pittsburg and Meigs Creek groups, everything points strongly to a deep basin in the eastern portion of the territory near the present Ohio River valley, extending west over a larger but much shallower basin, at the time these limestones were laid down. The main influx of fresh or drainage water was probably from the north and northwest, since the limestones are heaviest in the east and are condensed in the south, thin out to the west, and spread out or open up to the north, the intervals filling in with shale and sandstone.

There is much evidence of great atmospheric disturbance, or at least of the rapid migration of considerable bodies of water, at the time these limestones were formed. In many places a shale will take the place of a sandstone, or a sandstone or shale will completely replace a limestone for a short distance. When a sandstone replaces a limestone in this manner, it is usually false-bedded, and highly laminated. Thin strips of impure limestone come into a section frequently, and disappear again in a short distance.

This variation in the nature of a deposit at any given level is well shown in the first twenty-five feet under the Meigs Creek coal, of which the following sections are specimens.

		Feet.
Cumberland.	Shale	2
	Limestone	7
	Shale with kidney ore at base	15–20
Armstrong's Mill.	Shale with a little sandstone	23
Bellaire.	Gray sandstone, highly laminated and false-bedded	15–18
	Coal	1
	Limestone	8
Martins Ferry.	Shale, with some sandstone	20–25
	Limestone	8–9
Powhatan	Limestone	8
	Unknown (probably shale)	15–20
	Limestone	10

Each section starts with the bottom of the coal. This evidence of disturbance is less marked in the Meigs Creek horizon than in the lower or Pittsburg horizon.

There was evidently a period of quiet prior to the formation of the coals, during which time the rough floor of the basin was leveled and evened up by the sediments and gentle currents, since, while the coals do not lie in straight lines, they are comparatively much more even and less erratic in their location than other formations. The interval between the two coals is fairly uniform, varying from eighty-five to one hundred feet.

If we could see a cross section of this territory at a glance, the impression left on our mind would probably be much like the following illustration. This was not drawn to scale, or from exact data, or to represent any particular section, but was produced with a view of bringing more clearly before the reader the lack of conformity in deposition throughout the region, and to show that at the same elevation above the coal the same limestone is not always found. Sometimes the limestone at a given level above the coal is absent entirely, again it is thinner or heavier than it should be. At another point we may find a limestone ten to twenty feet higher than it should be, and in some cases another limestone entirely different in physical appearance and thickness may lie below it and at about the level where the other one was due. To the west, where the limestone strata thin out, it is, as a rule, only where two distinct groups of rocks get close enough together to be worked as one, that the thickness is sufficient to give them any value.

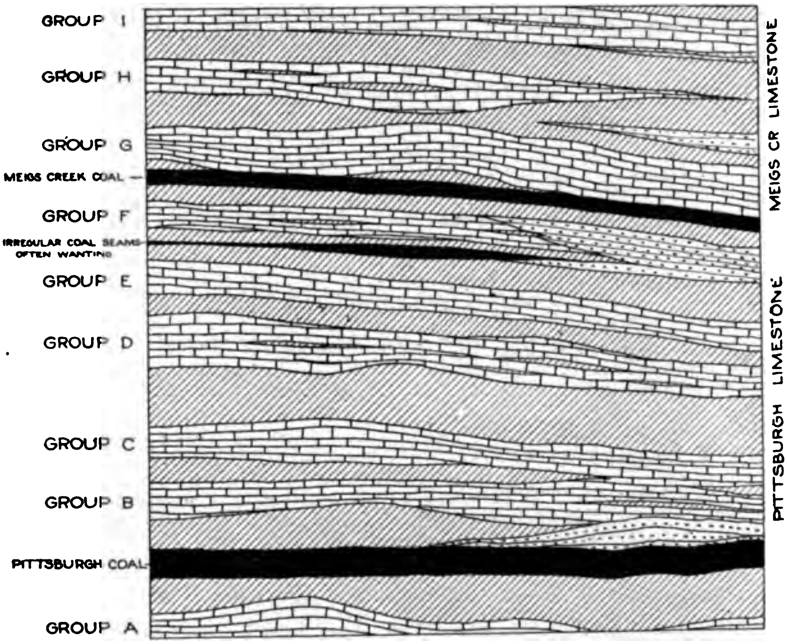

Figure 7.—Showing an ideal cross-section of the limestones of the Monongahela formation of South-eastern Ohio; the area covered is supposed to be several miles long, and the vertical range is approximately 160 feet. The fluctuation in thickness and the lack of continuity are the points which it is desired to bring out.

As has already been observed from the illustration, each horizon consists of a number of groups of limestone layers or strata; usually carrying shale partings, and the groups separated by beds of shale of greater or less thickness. In consequence of this, we do not find the thickness or general make-up of any one group constant throughout any wide area. Two groups frequently thin out and draw close enough together to be classed as one workable group. It must clearly be borne in mind, that the word group here is not used in a stratigraphical sense—merely an economic one. A group of limestones is found, where a sufficient number of limestone strata occur, to enable quarrying or mining operations to be carried on without the handling of so much interstitial material to make the work commercially unprofitable. No other signification attaches to this word in what may be said on the limestones of this formation.

As a further illustration of the exceeding variability of the strata, the three following records of core-drilled test holes in Mead township, Belmont county, are given. In each case, the bottom of the section is the horizon of the Pittsburg coal, which enables the correlation of the three to be easily made.

Record of Drill Hole No. 1

On Wegee creek, Lashley station, in north half of southeast quarter, section 2, Mead township, Belmont county, Ohio.

	Feet.
Surface	7.09
Gray shale	2.00
Gray sandstone	5.00
Shale, with lime nodules	1.00
Gray slate	3.00
Soft coal	0.04
Gray shale	0.07
Coal	0.04
Shale	0.03
Sulphur	0.01
Coal	1.02
Gray shale	0.09
Coal	0.08
Slate	0.07
Limestone	0.03
Cement rock	3.00
Limestone	2.00
Limy rock	0.05
Limestone	1.04
Cement rock	5.08
Black shale	0.02
Limestone	2.00
Gray shale	1.02
Limestone	3.09
Cement rock	0.10
Limestone	0.10
Green shale	4.00
Limy shale	0.06
Limestone, very hard	2.00
Dark rock	0.04
Limestone, hard	1.06
Soft gray shale	0.06
Green shale and fireclay, mixture	1.00
Black slate	0.07
Brown slate	0.06
Black slate	0.04
Sandy fireclay	1.06
Gray shale	2.00
Dark shale	0.04
Gray, limy shale	0.06
Blue limestone	1.03
Hard rock	0.06
Cement rock	1.00
Hard, limy shale	0.08
Limestone, blue	3.06
Limy shale and limestone	1.00
Limestone	0.10
Limy shale and limestone	1.06
Limy shale	2.06

Record of Drill Hole No. 1—Concluded.

	Feet.	
Limestone, mixed with shale	2.00	
Dark shale	1.06	
Green shale	2.06	
Dark slate and fireclay, mixed	0.06	
Gray shale	2.03	82.00 ft.
Roof coal	0.03	
Band	1.00	
Pittsburg, or No. 8 Coal	5.01	
Dark fireclay	0.04	
Dark, limy shale, hard	1.04	90.00 ft.

Record of Drill Hole No. 2

On Wegee creek, Crows station, in south half of northeast quarter, section 8, Mead township, Belmont county, Ohio.

	Feet.
Surface	7.00
Shale	2.06
Limestone	1.00
Shale	3.06
Limestone and shale, mixed	3.00
Green shale	4.00
Hard limestone	4.00
Gray shale	0.06
Cement rock	6.06
Limestone, mixed with shale	1.06
Hard, green soapstone	2.00
Soft, green shale	1.00
Dark, green rock	4.06
Green shale, sandy	2.00
Dark cement rock	3.06
Green shale	0.06
Limestone and shale, mixed	1.00
Hard, dark shale	0.03
Cement rock	1.00
Hard, dark shale	1.06
Limestone	0.06
Dark shale, hard	1.00
Cement rock	5.00
Hard, dark shale	0.03
Limestone	2.06
Dark shale	0.03
Cement rock	1.09
Hard shale and limestone	1.00
Green shale	1.06
Cement rock	3.03
Limestone	0.04
Cement rock	0.08
Limestone	0.03
Cement rock	0.06
Limestone	0.06
Dark, hard shale	0.06
Cement rock	7.00
Hard, green shale	0.09
Cement rock	2.09
Hard, dark shale	3.00
Hard, greenish shale	0.09
Cement rock	1.06
Hard, brown shale	1.03
Limestone	0.10
Hard, dark, limy shale	1.06
Between a limestone and cement rock	0.09
Hard, dark, limy shale	0.06
Limestone	0.07

Record of Drill Hole No. 2—Continued.

	Feet.	
Hard, dark, limy shale	0.06	
Limestone	0.02	
Limy shale	0.03	
Limestone	0.02	
Dark, limy shale, brown	1.06	
Fireclay	1.00	
Dark slate	0.03	
Coal	1.08½	92.00 ft.
Sulphur	0.00½	
Meigs Creek coal	2 04	
Black slate and sulphur	0.02	
Dark, limy shale	1.00	
Soft, gray shale	1.00	
Gray sandstone	3.00	
Gray shale with lime nodules	2.09	
Hard, gray shale, sandy	2.00	
Hard, dark-gray slate	5.06	
Brown slate, with little coal mixed	0.03	
Hard, dark slate	1.03	
Bone coal and slate, mixed	0.04	
Dark, gray slate	0.08	
Coal	1.03	
Band	0.03	
Coal	1.00	
Black slate	0.02	
Limy shale	0.09	
Limestone	0.06	
Dark, limy shale	0.04	
Cement rock	1.08	
Limestone	1.09	
Limestone and shale, mixed	0.05	
Limestone	1.00	
Cement rock	5.07	
Limestone	1.08	
Hard, gray shale	1.03	
Limestone, hard	3.09	
Gray shale	0.08	
Limestone	1.05	
Hard gray shale	1.00	
Sandy shale	0.06	
Limy shale	1.00	
Gray shale	2.00	
Limy shale, hard	1.09	
Limestone	1.09	
Green limy shale	0.07	
Limestone and shale, mixed	2.00	
Black slate	0.09	
Sandy fireclay, with lime nodules	0.09	
Black slate and sulphur	0.03	
Dark, limy shale	1.09	
Blue limestone	1.06	
Hard, gray shale	0.06	
Limestone	0.08	
Hard, dark shale	0.03	
Limestone	5.10	
Hard limy shale	0.03	
Limestone	1.00	
Hard, dark, limy shale	0.03	
Limestone, and shale mixed	0.08	
Limestone	1.03	
Limestone and shale, mixed	1.00	
Blue limestone	0.06	
Limestone and shale, mixed	0.06	
Soft shale, with lime nodules	1.06	
Hard, limy shale	1.04	

Record of Drill Hole No. 2—Concluded.

	Feet.	
Shale and lime nodules, mixed	0.10	
Hard shale and fireclay	1.04	
Bone coal	0.01	
Black slate and fireclay, mixed	1.02	
Black slate	0.04	
Roof coal	0.09	
Band	0.02	
Roof coal	0.06	
Roof coal and slate, mixed	0.07	
Band	0.08	
Pittsburg, or No. 8 Coal	5.05	
Limy fireclay	0.08	181.00 ft.

Record of Drill Hole No. 3

On Wegee creek, Irwin station, in south half of northwest quarter, section 14, Mead township, Belmont county, Ohio:

	Feet.
Surface	6.00
Limestone	0.06
Limestone and shale, mixed	0.09
Limy shale	0.06
Soft, gray shale	1.00
Sandy shale	1.00
Sandstone, gray	6.06
Gray shale	5.03
Limestone	0.06
Gray shale	0.03
Limestone	1.03
Soft, green shale	1.06
Fireclay	0.06
Dark shale	0.03
Sandstone, gray	10.00
Gray shale	1.06
Dark shale	0.03
Limestone	0.06
Hard, dark, limy shale	1.03
Limestone	1.04
Limy shale	0.03
Hard shale with lime nodules	1.04
Limestone	0.09
Limy shale	0.04
Limestone and shale, mixed	0.06
Limy shale	1.00
Limestone	0.06
Gray shale	0.06
Limestone	0.08
Gray shale	1.06
Dark, limy shale	0.08
Green, limy shale	0.08
Sandy shale	1.00
Limy shale	0.06
Limestone	1.03
Limy shale, hard	1.06
Limestone	0.04
Cement rock	1.09
Hard, limy shale and limestone	1.06
Dark limestone and shale, mixed	0.08
Gray shale	0.06
Limestone	2.03
Gray shale	1.03
Cement rock	3.06
Hard, dark, limy shale	3.09
Green shale	3.00
Red shale	0.03

Record of Drill Hole No. 3—Continued.

	Feet.	
Hard, green shale	1.00	
Limestone	0.08	
Hard, gray shale	0.04	
Hard, limy shale	0.09	
Cement rock	5.03	
Hard, green shale	0.09	
Hard, gray, limy shale	0.06	
Limestone and shale, mixed	1.00	
Gray sandstone	2.02	
Gray, sandy shale	1.06	
Cement rock	4.00	
Hard, dark, limy shale	1.09	
Limestone and cement rock, mixed	3.00	
Hard dark, limy shale	0.09	
Limestone and cement rock, mixed	1.09	
Hard, limy shale	2.00	
Limestone	0.08	
Hard, dark, limy shale	1.00	
Cement rock	4.00	
Hard, dark, limy shale	0.03	
Limestone	2.09	
Hard, gray shale	0.05	
Limestone mixed with shale	0.06	
Limestone and cement rock, mixed	1.04	
Hard, green, limy shale	0.05	
Limestone	0.08	
Green, limy shale	1.00	
Hard, dark-gray slate	1.04	
Cement rock	2.08	
Limestone	0.03	
Hard, limy shale	0.08	
Limestone, gritty	1.06	
Hard, limy shale	0.06	
Cement rock	2.00	
Hard, limy shale	0.06	
Limy shale, with little limestone	0.08	
Cement rock	2.00	
Gray slate	1.00	
Between a limestone and cement rock	3.06	
Hard, dark, limy shale	1.06	
Green, limy shale	0.07	
Hard, dark, gray sahle	2.03	
Hard, dark, limy shale	1.02	
Limestone, with shale, mixed	0.06	
Limestone	0.09	
Limy shale, hard	0.07	
Limestone	0.05	
Hard, limy shale	3.06	
Limestone and shale, mixed	0.05	
Fireclay	2.08	
Slate, dark	0.02	
Meigs Creek coal	3.09	137.78 ft.
Sandy fireclay	0.08	
Hard, limy shale	1.00	
Limestone	0.06	
Soft, gray shale with lime nodules	2.07	
Sandy shale	8.00	
Gray slate	7.03	
Brown slate	1.00	
Coal	0.05	
Band	0.03	
Coal	0.09	
Dark, limy shale	0.06	
Limestone	2.03	
Cement rock	1.03	

Record of Drill Hole No. 3—Concluded.

	Feet.	
Hard, limy shale	0.03	
Limestone	3.06	
Cement rock	4.03	
Hard, dark shale	0.03	
Limestone	2.00	
Gray shale	1.00	
Limestone	4.00	
Hard, limy shale	0.04	
Limestone	1.04	
Hard shale and limestone, mixed	0.10	
Hard, gray shale	1.00	
Limestone shale, mixed	0.06	
Limestone	1.10	
Hard, limy shale	0.09	
Green shale with lime nodules	1.00	
Fireclay	1.06	
Black slate	0.03	
Green and black slate, mixed	0.09	
Soft, clay shale	2.09	
Gray shale	1.06	
Sandy shale	1.06	
Black shale	0.03	
Hard, dark, limy shale	1.06	
Blue limestone	2.00	
Limestone, gray	2.06	
Hard, dark, limy shale	0.06	
Blue, limy shale, hard	1.03	
Limestone and shale, mixed	1.03	
Hard, limy shale	3.00	
Limestone and shale, mixed	0.03	
Hard, limy shale	2.00	
Limestone and shale, mixed	2.00	
Hard, limy shale	0.09	
Fireclay	1.09	
Hard, limy shale	0.06	
Fireclay and dark shale, mixed	0.11	
Black slate	0.04	
Roof coal	1.00	
Band	0.03	
Roof coal	0.05	
Band	1.11	
Pittsburg, or No. 8 Coal	5.00	
Dark fireclay	0.04	
Hard, limy shale	1.07	236.00 ft.

Further illustration of the structure of this field is given in the section at Armstrongs Mills, Washington township, Belmont county, in Chapter III. This section represents the extreme conditions in the eastern edge of the field, as nearly as any section can be said to do, where no close adherence to any type is found.

A similar section between Cumberland and Blue Bell, Guernsey county, represents the structure of the western edge of this district in the general way. It was measured over a considerable area, taking the thickness of the elements as they entered the line of travel.

Section from Cumberland to Blue Bell, Guernsey County.

	Feet.	Inches.
Coal blossom	..	..
Red shale	..	..

Section from Cumberland to Blue Bell, Guernsey County—Concluded.

	Feet.	Inches.
Buff limestone	..	..
Shale	..	..
Buff limestone	40–45	(above coal)
Purple and green shale	..	..
Shale	..	..
Coal, Meigs Creek	4	..
Fireclay	2	..
Limestone (sampled as No. 153)	7	..
Shale, with kidney ore at base	20	..
Sandstone	18–20	..
Coal	..	28
Fireclay	2	..
Limestone	1	..
Shale	1	..
Limestone	2	..
Shale	10	..
Limestone	1	..
Shale	2	..
Limestone	3	..
Yellow shale	20	..
Limestone	5	..
Shale	1	..
Coal	2	..
Unknown	10	..
Sandstone	31	6
Coal	3	..
Concealed	1	6
Nodular limestone	5	9
Sandstone	..	6
Limestone (Fossils, Crinoids and Orthis)	5	..
Purple shale and nodular limestone	10	6
Yellow shale (sandy)	15	9
Solid sandstone	20	..
Dark shale, with iron concretions	30	..
Drainage level	..	..

It should be about fifteen feet from here down to the Crinoidal limestone.

Beginning at the base of each horizon, we will roughly form the limestones which appear at approximately the same elevation above the coal into economic groups. The exposures and samples from each group will have, for the greater part at least, some properties in common.

The lower groups will pass the coal boundaries to the north and west, and fall back from them to the south. The higher groups will get well within the coal area on the north and west and reach much beyond it to the south and still be above drainage.

In this manner, the Pittsburg horizon is divided into six groups, which will be designated by the letters of the alphabet, beginning with A for the first one *under* the coal; and the Meigs Creek horizon into three, beginning with G.

Pittsburg Horizon, Group A.—This group was seen in workable quantity in but one point, Ames township, Athens county. The stone in this group lies from two feet to twenty-five feet below the Pittsburg coal. The only samples representing the group are numbers 141 and 176.

Group B.—This comprises a number of limestone strata, reaching a thickness of six to twelve feet, which lie from six to twelve feet above the No. 8 coal. This group is represented by sample No. 175, the constitution of which was given in the Martins Ferry section, Belmont county, Chapter III.

This group can be found in Cross Creek, Wayne, Smithfield, Wells, Warren and Mt. Pleasant townships, Jefferson county; Green, Cadiz, Athens, and Short Creek townships,Harrison county; Wheeling, Colerain, Pease, Pultney, Mead, York, the east half of Flushing, the north half of Richland, and most of Union townships, Belmont county.

Group C.—This group consists of seven to fourteen feet of limestone located twenty to thirty feet above No. 8 coal.

This group is represented by analysis No. 173. Sections of samples will be found in their respective counties in Chapter III. The limestone is to be found in Smithfield, Wells, Mt. Pleasant and Warren townships, Jefferson county; Short Creek township, Harrison county, and in all townships, except the western tier, in Belmont county.

Group D.—This group consists of from six to fifteen feet of limestone with a little shale, occurring forty to fifty feet above No. 8 coal. This is represented by samples No. 158, 161, 166, 167, 174, 171. The territory covered is practically the same as that given for B.

Group E.—This group is from six to ten feet thick and lies fifty-five to seventy feet above No. 8 coal. It is represented by samples Nos. 157, 160, 165, 170, 149, 147, 137, and 138. This is a very persistent group, and is to be found in the territory given for group B, and is above drainage a little farther south, and at a few points where only the Meigs Creek coal is mapped, but in the latter case is apt to be light.

Group F.—This group consists of six to fifteen feet of hard, light-blue stone, weathering to light brown, which is made up of beds from six to twelve inches thick, frequently interstratified with thin shale beds. This group when present is found seventy-five to eighty feet above No. 8 coal, or shortly below the Meigs Creek coal. In the eastern portion of the territory, this limestone is replaced for the most part by shale or sandstone, but the outcrops along the northern and western boundary of the Meigs Creek area, wherever exposed, show its presence.

It may be found in most of the following territory:

The west tier and south tier of townships, Belmont county; Milwood, Richland and Spencer townships, Guernsey county; Rich Hill and Meigs township, Muskingum county; greater part of Noble and Morgan counties; western tier of townships, Washington county; and east half of Athens county.

In the territory just named, there will no doubt be many places where it is either below drainage or is replaced by shale, or is too thin to be worked with economy. There is, however, a considerable body of it available when needed.

Where the coal was seen, this limestone was found to be close to it. At other places where the Meigs Creek coal was apparently absent, this stone showed up at about the proper elevation above the Pittsburg seam to place it near the Meigs Creek.

This is probably the most valuable group in either the Pittsburg or Meigs Creek horizon, since it is the only one in which the magnesium carbonate is low enough to make it available for portland cement manufacture. Aside from this, it frequently approximates the composition of portland cement, and is of a good physical character for this purpose, being very fine grained, apparently carrying no coarse quartz. The fact that in some localities it lies close enough to a four-foot vein of coal to be mined with it, also adds to its value. This group is represented by samples Nos. 136, 139, 140, 143, 153, 159, and 172. Nos. 140 and 159 are a little high in magnesium carbonate for use in the manufacture of portland cement.

Meigs Creek Horizon. Group G.—This group consists of a light gray to a very dark stone, so fine in grain as to have a fracture almost glassy in appearance. This stone is very brittle and hard, but does not stand the weather. The weather breaks it up into small rectangular blocks with many curved surfaces. This group is twelve to sixteen feet thick and lies immediately over the Meigs Creek coal. It is fairly constant in the east, but to the west it is thin or absent for the most part. The composition is shown in analyses Nos. 145, 154, 155, and 164. This stone is at its best in Washington, Mead, Smith, Richland, Pultney, Pease, Wheeling and Colerain townships, Belmont county, and Mt. Pleasant and Warren townships, Jefferson county.

Group H.—This group is of blue limestone interstratified with a little shale, and at some points one or two beds of buff stone, occurring fifteen to twenty-five feet above the Meigs Creek coal, and has a thickness of seven to thirteen feet. This group, while fairly persistent throughout the Meigs Creek area, is frequently too light to work, being cut out almost entirely by shale in many instances. Samples Nos. 144, 156 and 168 give an idea as to its make-up and composition where thick enough to work.

Group I.—This group is six to thirteen feet thick. It is seldom absent at an elevation of thirty to fifty feet above the Meigs Creek coal. It is readily recognized; it is a buff limestone, resembling to some extent in appearance a very fine grained sandstone. It breaks with a conchoidal fracture. In most cases, there are at least two beds of this stone, which are each from twelve to twenty-four inches in thickness. The balance of the group is made up of various sorts of limestone and frequently a light shale parting or two.

The samples from this group are: Nos. 146, 148, 150, 151, 152, 162, 163, 169 and 183.

This group is found in the western half of Monroe county; Sharon township, Noble county; Meigsville township, Morgan county; southeast portion of Spencer township, Guernsey county, and probably on either side of a straight line joining this point and Powhatan, Belmont county.

The limestone, which comes in about twenty-five to thirty-five feet under the Meigs Creek coal, is the most constant of any of the series as to its location throughout the field, while the ledge immediately over the Meigs Creek coal is a close second.

Chemical Composition.—As has been stated elsewhere, the prime object of this survey was to study the limestones of the state with special reference to the portland cement industry. This required that the sampling of the limestones should be done with due regard to their average composition, or in such a manner as to enable one to see what the composition of the material would be en masse, and not by picked samples, and also, that sampling should take due cognizance of the occurrence of the stone with reference to winning. Owing to the rugged nature of the country in which these limestones occur, it is seldom that any large area could be won by open quarrying. Therefore, the only way to win them on a large scale will be by mining, and mining conditions must govern in determining what could be won with economy. It has been determined that less than four feet in height is expensive of operation in mining. Therefore, no limestone less than six feet in thickness was sampled, unless there was a roof stone over it, which would stand up well under the strain incurred in moving all of the limestone.

Since the sampling was controlled mainly by considerations of economic mining of the stone, the analyses will not do as much toward establishing the uniformity of composition, or the lack of it, in any given seam or ledge of limestone throughout the region studied, as they would have done had the shale, which is included in many of the samples, been left out. The thinner shale beds, which are frequently interstratified with the limestone, often cut out and come in again within a distance of a few hundred feet. In mining the stone, it would be practically necessary to include these thin bands of shale, and for that reason they have been included here. Naturally this reduces the accuracy of our knowledge of the composition of the stone layers, by themselves. It does not, however, change the broad essential facts of constitution.

Table VIII.—Analyses of the Limestones

Group A—2 to 25 Feet Below the Pittsburg Coal.

Serial number of sample.	Location of sample	Thickness and relative position of the stratum represented by this sample.
141	Athens Co., Ames Tp	14 feet 6 inches thick
176	Jefferson Co., Steubenville	12 feet thick

Group B—6 to 12 Feet Above the Pittsburg Coal.

175	Belmont Co., Martins Ferry	8 to 10 feet above coal, 10 feet thick

Group C—20 to 30 Feet Above the Pittsburg Coal.

173	Belmont Co., Martins Ferry	26 feet above coal, 13 feet 6 inches thick

Group D—40 to 50 Feet Above the Pittsburg Coal.

158	Belmont Co., Powhatan	10 feet thick
161	“ “ Bellaire	7 feet thick
166	“ “ Armstrongs Mills	5 feet thick
167	“ “ “ “	8 feet 6 inches thick
171	“ “ Barnesville	6 feet thick
174	“ “ Martins Ferry	7 feet thick

Group E—55 to 70 Feet Above the Pittsburg Coal.

137	Athens Co., Big Run	14 feet thick, 75 feet above No. 8 Coal
157	Belmont Co., Glencoe	10 feet thick, not far under Meigs Creek coal
160	“ “ Bellaire	8 feet thick, 20 feet under Meigs Creek coal
165	“ “ Armstrongs Mills	8 feet thick, 25 feet under Meigs Creek coal
170	“ “ Barnesville	7 feet 6 inches thick, 25 feet under Meigs Creek coal
149	Morgan Co., Unionville	7 feet six inches thick
138	Washington Co., Wesley Tp	10 feet 6 inches thick, south end of township
147	“ “ Waterford	11 feet thick

Group F—75 to 85 Feet Above the Pittsburg Coal.

136	Athens Co., Amesville	13 feet thick
143	“ “ Canaanville	14 feet 6 inches thick
159	Belmont Co., Powhatan	8 feet thick, just under Meigs Creek coal
172	“ “ Henrysburg	7 feet thick
153	Guernsey Co., Cumberland	7 feet thick, under Meigs Creek coal
139	Washington Co., Wesley Tp	15 feet 6 inches thick, middle of township
140	“ “ “ “	11 feet thick, north end township

of the Monongahela Formation.

Group A—2 to 25 Feet Below Pittsburg Coal.

Constituents.					Total.	Remarks.	Serial number of sample.
Silica.	Alumina.	Ferric oxide.	Carbonate of calcium.	Carbonate of magnesium.			
4.62	1.44	1.00	90.90	1.60	99.56		141
12.50	10.11	4.19	61.00	5.86	93.66		176
Group B—6 to 12 Feet Above the Pittsburg Coal.							
13.60	3.69	1.95	69.60	10.90	99.74	Glens Run.	175
Group C—20 to 30 Feet Above the Pittsburg Coal.							
19.68	6.77	1.63	61.50	9.00	98.58	Glens Run.	173
Group D—40 to 50 Feet Above the Pittsburg Coal.							
14.40	4.73	2.65	59.40	18.39	99.57		158
12.36	3.92	1.24	70.90	10.75	99.17		161
26.10	9.64	1.30	45.70	15.45	98.19		166
17.02	4.56	1.74	59.78	15.98	99.08		167
16.10	5.74	2.28	51.25	23.02	98.39		171
8.74	3.30	1.30	70.40	15.30	99.04		174
Group E—55 to 70 feet Above the Pittsburg Coal.							
14.88	5.41	1.81	67.45	9.15	98.70		137
11.20	3.46	0.80	68.00	15.75	99.21		157
9.86	2.84	0.60	76.10	11.00	100.40		160
10.20	2.41	1.13	73.57	12.19	99.50		165
14.06	4.33	1.13	66.31	12.71	98.54		170
15.80	3.40	0.90	71.88	8.54	100.52		149
18.46	6.33	2.47	63.10	8.82	99.18		138
11.60	3.17	1.25	73.60	10.00	99.62	Close to drainage level.	147
Group F—75 to 85 feet above the Pittsburg Coal.							
22.90	8.17	2.07	62.29	2.69	98.12		136
14.50	4.56	1.40	76.78	1.21	98.45		143
14.94	4.57	1.95	70.15	8.22	99.83		159
3.14	0.74	0.90	92.48	1.84	99.10	20 feet above 22 in. coal	172
7.24	1.48	1.20	87.47	2.40	99.79		153
25.28	8.47	1.87	58.17	3.70	97.49		139
14.32	4.82	1.66	73.67	5.20	99.67		140

Table VIII—Analysis of the Limestones

Group G—Immediately Above the Meigs Creek Coal.

Serial number of sample.	Location of sample.	Thickness and relative position of the stratum represented by this sample.
164	Belmont Co., Armstrongs Mills	15 feet thick
155	" " Bellaire	14 feet thick
154	Noble Co., Sumerfield	10 feet thick, 35 to 45 feet below coal vein, 2 feet thick
145	Washington Co., Lowell	7 feet thick
	Group H—15 to 25 Feet Above the Meigs Creek Coal.	
168	Belmont Co., Armstrongs Mills	13 feet thick
156	" " Glencoe	12 feet thick, 24 feet above Meigs Creek coal
144	Washington Co., Cow Run	7 feet thick
	Group I—30 to 50 Feet Above the Meigs Creek Coal.	
162	Belmont Co., Armstrongs Mills	6 feet 6 inches thick
163	" " " "	13 feet 3 inches thick
151	Monroe Co., Quarry P. O.	7 feet just above coal blossom
152	" " Mechanicsburg	6 feet thick
169	" " Woodsfield	11 feet thick
183	" " Fly P. O	11 feet 6 inches thick
148	Morgan Co., McConnellsville	11 feet, on Four Mile Run
150	" " Stockport	11 feet 6 inches thick
146	Washington Co., Lowell	2 feet 6 inches, just above sample 145

Analyses of the Limestones of the Monongahela

Serial number of sample.	Location of sample.	Description of sample.
a	Belmont Co.	Parkers cement stone (Dr. P. Schweitzer, 1870)
b	" "	Parkers cement stone (Wormley, 1870)
c	" " Warnocks Station	Cement limestone (Wormley, 1870)
d	" "	Wegee cement rock (Wormley)
e	" "	Wegee cement rock (Wormley)
f	" "	Limestone, 18 inches above cement rock (Wormley)
g	" " Putterey	J. F. Hutchinson's cement rock (Wormley)
h	" " Bellaire	Cement stone (N. W. Lord, 1887)
i	Muskingum Co., New Concord.	Probably Ames limestone, maybe above: (Wormley)
j	Washington Co., Salem Tp.	Whipples Run, near Duck Creek

of the Monongahela Formation—Concluded.

Group G—Immediately Above the Meigs Creek Coal.

Constituents.					Total.	Remarks.	Serial number of sample.
Silica.	Alumina.	Ferric oxide.	Carbonate of calcium.	Carbonate of magnesium.			
25.46	10.11	1.25	45.40	15.53	97.75		164
25.12	9.48	1.60	36.35	25.18	97.73		155
16.44	5.15	1.65	62.30	13.01	98.55		154
14.84	3.93	1.65	65.09	14.54	100.05		145

Group H—15 to 25 feet Above the Meigs Creek Coal.

Silica.	Alumina.	Ferric oxide.	Carbonate of calcium.	Carbonate of magnesium.	Total.	Remarks.	Serial number of sample.
17.10	4.90	1.24	58.93	16.87	99.04		168
33.68	10.06	2.08	41.20	10.19	97.21		156
12.60	4.89	2.44	67.35	10.41	97.69		144

Group I—30 to 50 Feet Above the Meigs Creek Coal.

Silica.	Alumina.	Ferric oxide.	Carbonate of calcium.	Carbonate of magnesium.	Total.	Remarks.	Serial number of sample.
29.16	8.43	2.69	44.23	13.56	98.07		162
25.88	7.06	1.84	47.70	15.84	98.32	4 feet above 168.	163
14.92	3.83	2.47	47.85	30.41	99.48		151
23.53	7.77	2.79	40.79	23.71	98.59		152
15.20	5.02	1.30	55.80	21.16	98.48	Buff.	169
26.48	7.28	2.30	50.50	10.75	97.31		183
8.24	2.62	2.50	67.48	18.24	99.08	Buff.	148
14.66	3.51	1.85	67.30	12.78	100.10		150
16.80	4.76	3.00	44.08	28.44	97.08		146

Formation, Compiled From Various Sources.

Constituents.					Total.	Remarks.	Serial number of sample.
Silica.	Alumina.	Ferric oxide.	Carbonate of calcium.	Carbonate of magnesium.			
8.47	4.85	3.10	72.10	11.15	99.67	Moisture and loss, 0.33.	a
29.80	13.80	....	41.20	15.36	100.16		b
30.60	13.00	....	40.60	15.18	99.38		c
24.00	7.00	....	37.90	30.47	99.37		d
17.40	6.20	....	51.80	23.94	99.34		e
8.60	4.90	....	80.70	5.69	99.89		f
31.20	6.60	....	37.80	23.89	99.49		g
16.41	5.44	3.38	46.52	26.40	98.15		h
42.29	8.28	....	49.35	....	99.92		i
19.10	8.56	....	47.70	19.40	94.76	Combined water, 2.70.	j

A study of the data set forth in Table VIII clearly shows the effect of the method of sampling, i. e.: the inclusion of the bands of shale which occur between the bands of limestone, which it was desired to bring into the sample. These shale bands run the silica and alumina in these analyses up to a figure markedly above what the limestone themselves would show. However, it is probably true that these limestones average high in sandy and clayey materials, when taken by themselves. On the other hand, it is improbable that the shales contain as much magnesia as the limestones do; hence, the magnesia percentages in these analyses are probably lower than would be the case if the limestone bands alone had been included in the samples.

There seems to be no close adherence to a type, from group to group, or group by group. Group F from just under the Meigs Creek coal shows a uniformly low magnesia content, but wide variations in silica and alumina.

From the facts before us, we can only generalize to the extent of saying that the limestones of the Monongahela formation are generally earthy, very generally magnesian, and very rarely pure. The magnesia, while fluctuating from two per cent. to thirty, averages about twelve to fifteen per cent.

Uses.—The use to which these stones have been put is exceedingly limited, and indeed there seems but little likelihood that new uses of importance are soon to arise which will exploit them in an extended scale. Building stone can be obtained from them, in many places and of good quality. But, as the same hills contain also sandstones and freestones in abundance, the harder limestone is not likely to be used for this purpose.

For lime, the earthiness, the gray color of the product and the long and thorough burning necessary to get them into a condition to slake, makes them undesirable.

For portland cement, with the exception of Groups F and A, there seems no promising material whatever. The limestones of these two groups do promise fairly well so far as their chemical constitution is concerned. The thickness is also within profitable limits for economical mining. The locations are at present generally inaccessible to rail, but this is a matter which can be rectified in various ways. The fuel supply from local sources is generally sulphury, and would be used for cement with reluctance.

For hydraulic lime or roman cement there seems a much wider field. The materials have already been used for this purpose at Barnesville and at Bellaire. Both industries are now dead, and could not be revived on the old basis. But roman cements have a definite place in engineering economics. They are inferior to portland cement for many purposes, but when they go under ground for foundations, and are used as mortar for rough stone masonry, they are good enough, if not as strong as portland. Their cost of production can always be kept lower than portland, if the same grade of engineering skill and intelligence is applied to the manufacture. At present, these roman cements are burnt in tall kilns, like limekilns, which make an uneven product for two reasons: first, irregular composition of raw material and no chemical control. Second, irregularity of burning with no tests to show same. Much material gets through with too little heat, and is not much better than common lime. Other portions become louped, or stuck together, forming a nearly inert calcium bisilicate, midway between the trisilicate of the portland and the lower silicate of the roman. The use of the rotary kiln, with accurate control of the temperature and rate of flow, and also the use of proper care in sorting the crude material, and in the final pulverizing, will do much to put this class of material on the market on a different basis from what it now occupies. The irregularity of composition. burning and physical behavior, makes the roman cement of today a somewhat risky material, where work of importance or precision is contemplated.

It is a peculiar and as yet but poorly explained fact, that magnesia may constitute a considerable proportion of a roman cement with good results. Therefore, the principal disqualifications of the present group of limestones for portland cement is removed for roman cement manufacture.

CHAPTER V.

THE USES OF LIMESTONE IN OHIO

BY S. V. PEPPEL.

BUILDING STONE.

Ohio is bountifully supplied with limestones of excellent quality for building and construction work. Much of this stone is so placed by nature as to favor economic winning, and there are innumerable locations favorably situated with reference to transportation facilities. The largest development has naturally occurred where transportation to good markets has been afforded at low rates. One of the prime factors in the promotion of the growth of the largest limestone producing center in the state for construction work was cheap transportation. From the table which follows it may be seen that Kelley's Island, Marblehead and Sandusky have outstripped other centers of equal area. While water transportation has been a prime factor in producing this result, it has not been the sole cause of this large development. These properties have had an aggressive business management, and the plants have been supplied with the best of modern equipment. Aside from the above, the stone was of such quality as to be very desirable for construction work as well as of such a composition that there need be no waste from small rock and spalls, as they could all be used for manufacture into lime, or if too small for that, they were ground and sold to the glass trade for flux.

The number of quarries operating on the Corniferous for building stone is far less than for those on the lower element of the Niagara group, yet the total production is much greater for the Corniferous than for any other limestone formation in the state. While the Corniferous, the Waterlime or Monroe and the Lower Niagara are the formations chiefly used for this purpose, all of the limestones represented in the geological scale for western Ohio are used to some extent for construction material. In many cases, however, the production is only of local importance.

From the Carboniferous formation, the great sandstone and freestone output is derived, which is much the largest part of the quarry output in the state for building purposes, but very little of the Carboniferous stone quarried for this purpose is limestone.

Ohio produces altogether 1,325,000 perches of limestone annually for building purposes. The weights sold for a perch vary from 27,000 to 40,000 pounds. Rubble and light building stone sells for eighty-five cents to a dollar per perch at the quarry. Bridge and heavy building stone at $1.35 to $1.75. Stones for specific purposes command much higher prices. When stones are cut at the quarry, the cost of dressing is added to the above price. For curbing, this is twelve to fifteen cents per linear foot; for window caps, sills and door caps, etc., sixteen to twenty cents per linear foot; for steps, etc., eighteen to twenty-five cents per square foot.

The Quarrying or Winning of Limestone for Building Material.—The typical method of winning building stones in Ohio is to use hand drills and wedges to break the stones out. This crude method of operation is still the mainstay of the Ohio building-stone quarryman, for two reasons:

First: The quarries are in the main comparatively small or are operated in conjunction with the production of lime or crushed stone. Only a few quarries in the state are working more than ten to fifteen men on building stone alone, and many only employ four to five men.

Second: This stone, which aside from the few very large quarries comes mainly from the base of the Niagara group, occurs in such a condition as to be readily obtained in desirable dimensions by the most crude methods. It occurs for the most part in loosely-bedded, even layers of desirable thickness, with occasional crevices or dry cracks to furnish working faces. The stone while still in the quarry is usually soft and easily penetrated by the drill. The depth of hole required is always slight, usually only five or six inches and seldom as much as twelve inches. For the above reasons, methods of hand drilling, which would be entirely inadequate when working in most rock formations, are not only feasible, but effective and rapid, as practiced in Ohio. It is remarked how quickly and accurately a man skilled in the use of these long hand drills can sink a hole. Nor is the labor so severe on the back of the driller, as in the ordinary hand drilling practiced on harder rock, where a short drill is held and rotated by hand, while a heavy hammer is used or another man wields a sledge.

The limestone quarryman's drill consists of a light steel bar, about six feet in length, sharpened at one end to the ordinary cutting point used for the short drill bit. The operator stands up straight, and sinks the hole by raising and dropping the drill, turning it part of a revolution with each stroke. The workman does not seem to put much effort in the downward or driving stroke. The main energy expended seems to be in lifting the drill up for successive strokes.

In the Corniferous and Waterlime (Monroe) belts, the bedding of the stone is much tighter, and more vigorous methods are necessary for the economic winning of the stone. In these formations but few quarries are operated for building stone alone, and as a rule compressed air or steam drills are available for the heavier work. In some cases in the

Waterlime, as at Greenfield, "pop shots" are resorted to to open up working faces, since the bedding is exceptionally tight at this point. Also the stone makes a good lime, and hence there is no waste occasioned by the spalls from these shots. This quarry is among those using modern equipment, and as may be seen from the table at close of this chapter, it is one of the larger producers of building stone in the state. The great majority of the output credited to Highland county comes from this point. The drilling is chiefly done with a tool known as the quarry bar. It is is an ordinary steam or compressed air drilling machine mounted on a horizontal rod, or bar, so that any number of holes may be put in in a straight line covering the length of this supporting rod at one setting without shifting the mounting of the drill or drills.

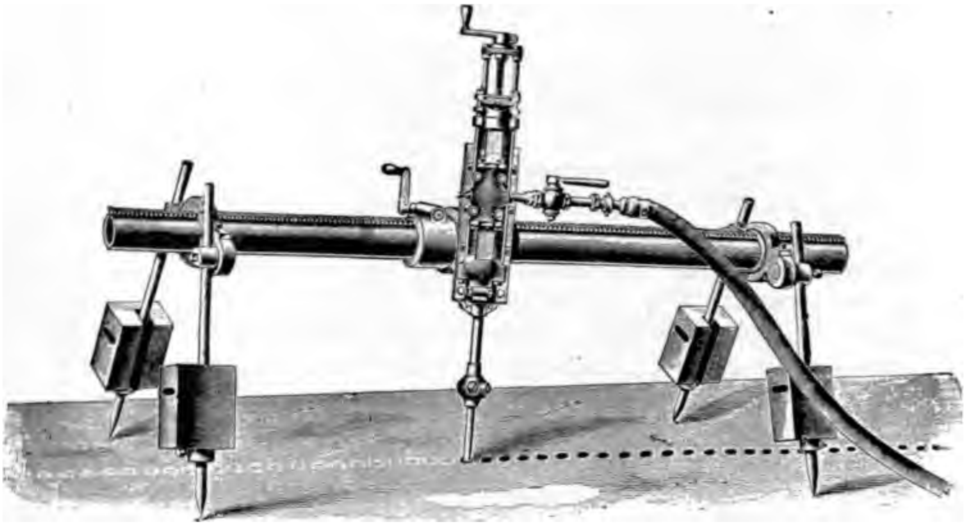

Figure 8.—Quarry bar, or line drill.

The Miami Stone Company operating in Lucas county, between White House and Waterville, is using another modern implement in disengaging the stone, viz: a channeling machine. This type of machine is much used for the quarrying of oolitic limestone in Indiana, in the marble quarries of the United States and in the great Ohio sandstone quarries. These machines are most used where the conditions are different than those existing in Ohio limestones. It is a question whether they introduce much economy in working a well stratified stone occurring in comparatively thin beds. They are designed for use in quarrying huge blocks from massive beds of stone. The blocks usually cut are about six feet by six feet by four feet or larger. The quarry cost for channeling, labor, fuel, and loading is about six cents per cubic foot in the oolitic limestone district of Indiana, and considerably more than

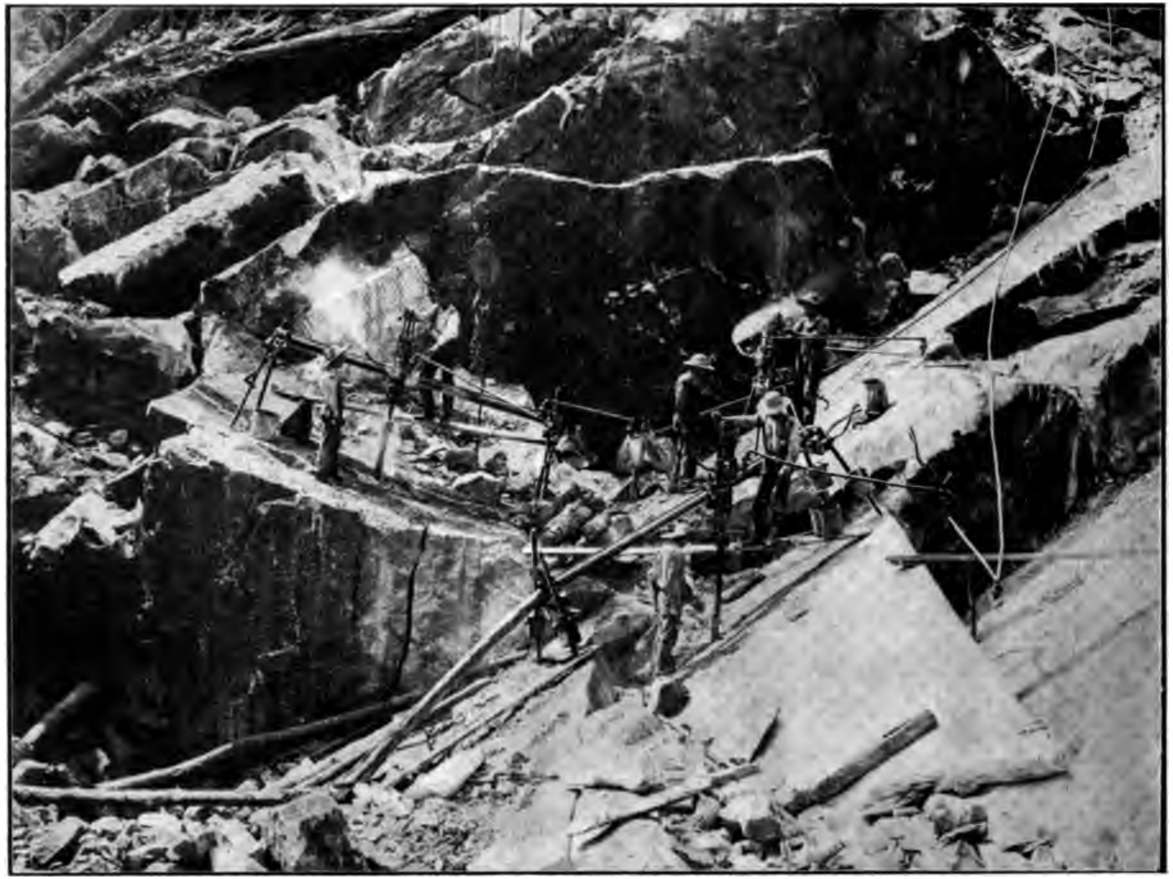

Figure 9.—Showing quarry bars at work in a southern marble quarry.

this in marble quarries. This cost would be considered excessive for Ohio limestone quarries, but a channeling machine operating on the latter stone, where key blocks and beds would not have to be raised, would produce stone at a much lower cost than the above figures. With loose, even-bedded stone, in thin layers, it is likely that the channeler does not introduce much if any economy. The machine consists of a boiler and an engine, mounted on a track so as to be driven by its own power back and forth, the engine at the same time operating a set of chisel-shaped heavy bars which are lifted and allowed to fall, or are forced down by steam or air pressure as well. These bars are held at a definite height by clamps, and chop the channel to that depth as the machine advances. The cutting bars are let down as fast as needed for new cuts. A number of bars are clamped together to make the chopper on each side of the machine. These blows repeated rapidly soon cut a trench or channel two inches wide and as deep as convenient, usually four feet or less. By this machine, a block may be cut loose from the matrix on all sides, and lifted out of its bed without any strain or shock whatsoever. The cut may be extended straight ahead the full length of the track, which may be then extended, or moved at right angles, and cross cuts made.

This machine would not be economical on Ohio limestones, unless a number of layers could be cut through at one time.

Table IX—Production Per Annum of Building Stone, by Formations.

	Perches.
Carboniferous	1,153,564
Lower Niagara	122,569
Waterlime	32,245
Hudson River	11,000
Clinton	1,406
Upper Niagara	4,500
Total	1.325,284

Stone not sold by the perch was roughly estimated in perches.

CRUSHED STONE.

The last five years has witnessed an enormous increase in the crushed-stone industry in the state. Many quarries are operated for this product alone; others run crushers only as a means of disposing of the waste rock, such as spalls from building stone, and pieces too small to go into the lime kiln.

Crushed stone is made from all of the limestone formations in the state; the major portion, however, is supplied by quarries located on the Corniferous and Waterlime. Crushed stone has three distinct fields of usefulness, viz: flux, road-metal and railroad ballast, and as the main constituent in concrete work of all classes. The growth of the latter use

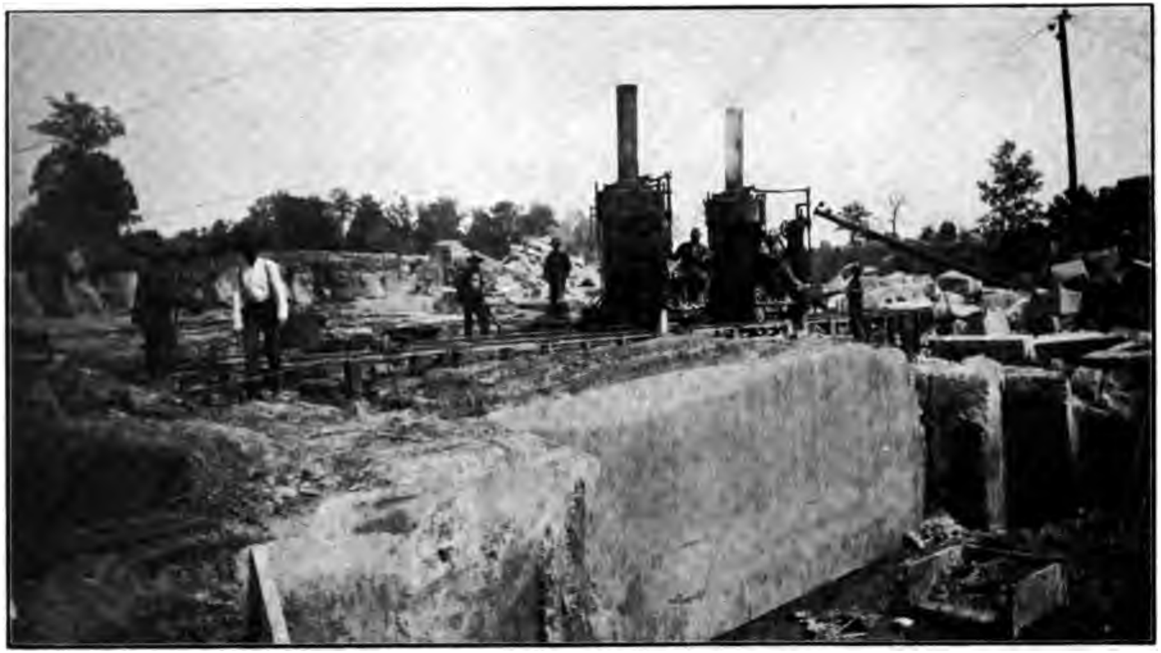

Figure 10.—Channeling machine at work.

has been phenomenal in the last few years. Concrete, consisting of mixtures of crushed rock, sand and lime, is being made into monolithic structures of all sorts, some reinforced with steel, others not. Much concrete is also going into solid blocks of special shapes. Hollow concrete blocks are now made, closely resembling cut stone and are being laid in the wall at a lower cost than that for which the stone could be laid down on the ground.

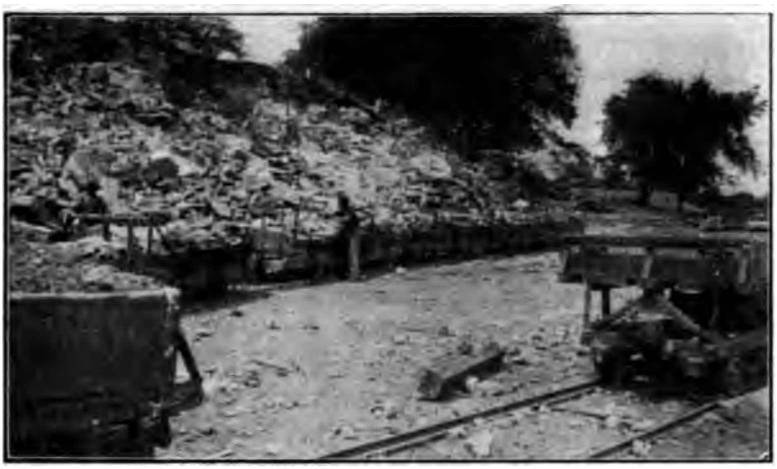

Figure 11.—Casparis quarries, Columbus, O. Loading the product of a blast into cars.

When used as a flux, it enters three industries.

First: It is shipped up the lakes to the copper smelters.

Second: The blast furnaces and foundries of Ohio and western Pennsylvania use enormous quantities of Ohio limestone, for fluxing the impurities of iron ores into a fusible slag, from which the molten iron may separate by gravity.

Third: For the manufacture of bottle and window glass. For this purpose, much limestone is crushed and ground to a twenty mesh or finer powder, the spalls and refuse too small for advantageous burning in the limekiln usually being utilized in this way.

The main requirements laid upon limestone to be used for metal smelting is first a fairly high content of calcium carbonate and correspondingly low silica and alumina; second, practically no phosphoric acid or sulphur. The Corniferous limestone is the only formation which meets these conditions in the large way. There are a few localities in the coal measures, such as Hanging Rock, Scioto county, and Lowellville, Mahoning county, where limestone is found which also meets these requirements.

A little dolomite is used as a flux in some special industries, and for furnace linings in the basic process of steel manufacture.

For use as a material in the manufacture of bottle and window glass, the requirements are somewhat different. The strongest requirement is that the oxide of iron must be absent, or at most only faint traces of it. A high proportion of calcium carbonate is desirable, and usually insisted upon. Practically no dolomite is ground in the carbonate form for this type of glass, but large quantities of it is ground in the calcined or lime condition for use in the manufacture of flint and plate glass.

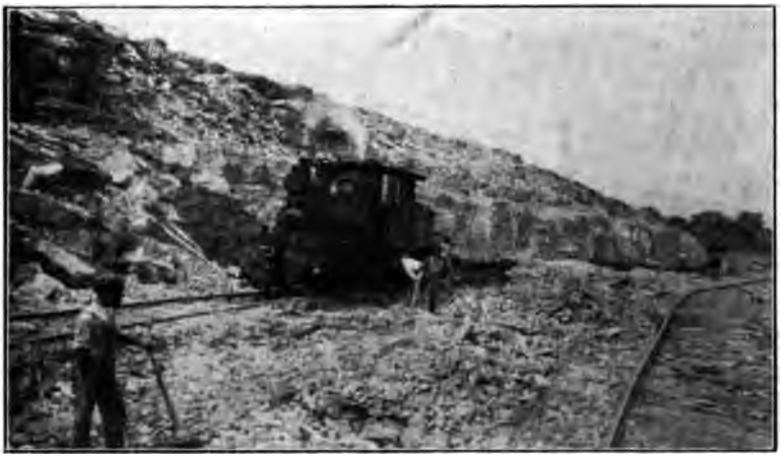

Figure 12.—Casparis quarries, Columbus, O. Hauling the rock to the crusher.

When the entire quarry output is of such a composition as to make it desirable in the manufacture of bottle and window glass, and the quarry as operated is clean enough—i. e., free from contamination from stripping, and mud seams—as is the case in a few Ohio quarries, the screenings, dust, etc., from the crushers is run to the grinders and prepared for the glass trade. Where the stone is contaminated by clay or gravel from the stripping, the dust and finest screenings must be discarded for this purpose. The number of quarries where everything can be used for this purpose is small. The prevailing method of fine grinding after the first crushing is to use either buhr mills, like the Sturtevant vertical rock emery mill, or impact pulverizers such as the Williams mill. The Corniferous formation furnishes most of the ground limestone which is sold from Ohio quarries to the bottle and window glass factories.

Almost any of the limestones of the state will make good road metal, or railroad ballast, and material for use in concrete construction. The railroads are the largest consumers of this product. The Waterlime formation probably furnishes the most railroad ballast, but not the largest amount of crushed rock for all purposes.

Aside from the above, each year sees more crushed limestone, especially the screenings, used in concrete construction. A great deal of the ground screenings from ballast and flux crushers is now taken by fertilizer manufacturers, and chemical works, for neutralizing acids.

There were crushed in Ohio in 1902 about 2,954,058 cubic yards of stone, including all kinds. This amount was made up from the following amounts from each formation:

Table X—Production of Crushed Stone, by Formations.

	Cubic yards.
Corniferous	1,717,580
Waterlime	711,190
Upper Niagara	44,730
Lower Niagara	58,365
Clinton	33,454
Hudson River and other formations	388,739
Total	2,954,058

The weight of crushed stone sold for one cubic yard varies from 2,240 pounds to 2,800 pounds.

The average price paid for labor around the quarries and lime plants was, for 1901, 14.8 cents per hour; for 1902, 16.3 cents per hour. Average labor cost remained about the same for 1903, 1904, and 1905 as for 1902.

The crushed stone industry of Ohio is large and its output ranks well to the front among the list of stone-producing states. Ohio possesses two stone-crushing plants which, if not the largest in the United States, are certainly among the greatest. One of these is located at Marblehead, near Sandusky; the other at Marble Cliff, near Columbus. The latter is the property of the Casparis Stone Co., which is one of the largest operators in the production of crushed stone, fluxed rock, rubble and dimension stone in the United States. While this company operates quarries in Ohio, Indiana and Illinois, their largest crushing plant is at Marble Cliff, Franklin county, Ohio. This plant has been remodeled and rebuilt within the last few years, and is one of the most modern in equipment. For the coarse crushing, or for the manufacture of flux and ballast, the Allis-Chalmers equipment or gyratory crushers of the Gates type are used. For the fine pulverizing, both Williams and Jeffreys impact pulverizers are in use. The present management speaks very highly of the efficiency of the impact pulverizer made by the Jeffrey Manufacturing Company. This was formerly known as the Scoellhorn-Albrecht pulverizer, manufactured at St. Louis, but has been bought, improved and modified by the Jeffrey Manufacturing Company. The plant has a crushing capacity of over 4,000 tons per day. The power used at this plant for general purposes is about 750 horse power, all generated by Corliss engines. The Ingersoll-Rand compressors are in use and require about 400 horse power. The crushing plant consists of Gates crushers No. 9, No. 7½, two No. 6s and two No. 4s, and in the grinding department three pulverizers are in use.

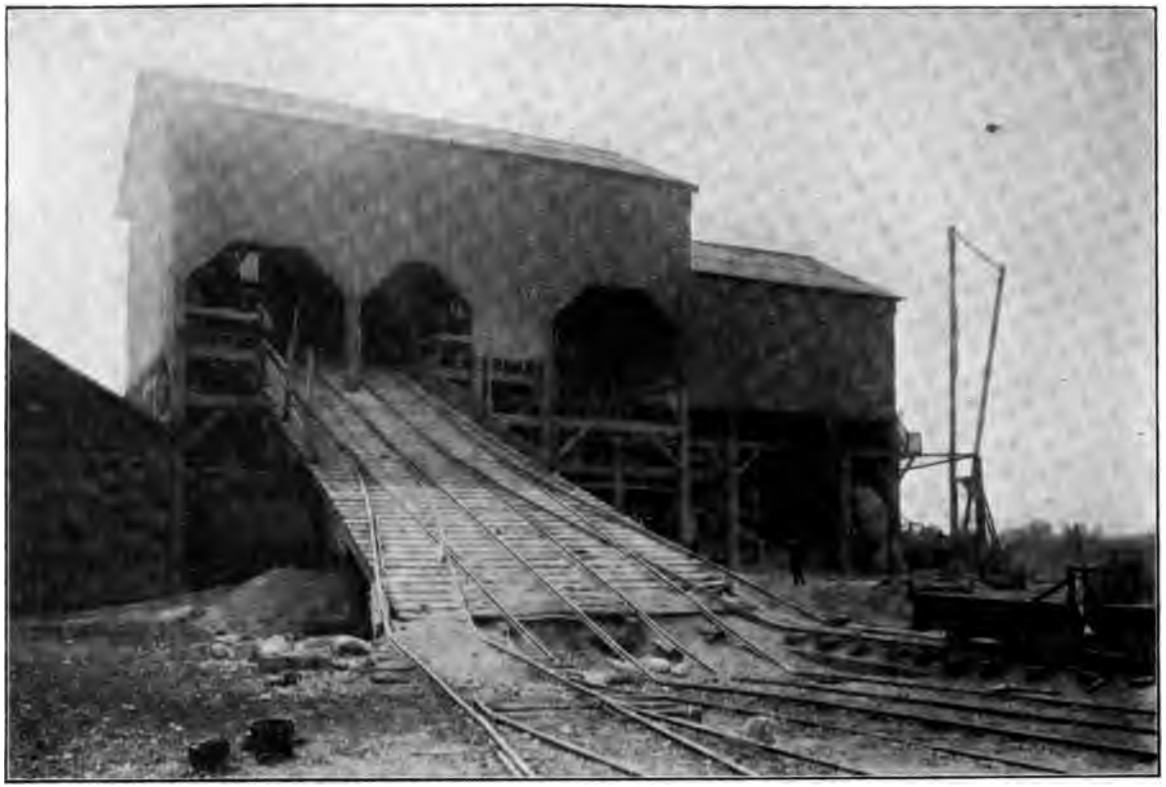

Figure 13.—Casparis quarries, Columbus, O. The crushing plant, showing tracks for the incoming coarse stone.

Machinery and power is used wherever possible and labor cost reduced to a minimum. Automatic dumps are arranged for the cars which come up to the crusher laden with stone. At other points air hoists are used to dump the cars. The quarry is a network of track, and small locomotives haul the cars to the base of the incline that reaches the crushers. This quarry and plant is one of the most economical in operation that can be found anywhere in the state. This plant is also probably the largest shipper of flux stone in the state. It is located on the Corniferous formation, which is peculiarly well adapted for this purpose, both in physical character and composition.

The main products shipped are flux rock, ballast, crushed stone for concrete, ground stone for glass manufacture, fine stone and dust for surfacing roadways and ground limestone for fertilizer works. To be used for flux, the stone must be broken enough to pass a four-inch ring and remain on a two-inch ring. Ballast stone passes a two and one-half inch ring and lodges on a three-quarter inch ring. For concrete work all material should pass a one and one-fourth inch ring. For surfacing roads, a three-fourths inch ring is used and all which passes through, including the dust is used. For fertilizer manufacture, only very fine material is shipped, and for the glass trade the stone is reduced to 22 mesh. It is probable that over half of the product of the Marble Cliff quarries is shipped for fluxing purposes, about 0.3 to 0.4 for ballast, the balance being used for ground limestone and for concrete and other purposes. While dimension and rubble stone are taken from these quarries, and area matter of some importance there, they are not nearly so important as the crushed stone output.

LIME.

The lime industry of Ohio is large, the product being used not only for local consumption, but also being shipped into adjoining states. In smaller amounts it enters the markets of a majority of the states of the Union, and in the hydrated form it has entered the export trade. The quality of Ohio limes is widely and favorably known. Ohio has been a large producer of lime of the highest grade for a great many years, and has been putting on the market every type of lime except perhaps the extreme high-calcium, low-magnesia limes. The earlier chapters have shown that Ohio has good locations for the production of this type also. Should the chemical industries of the country show sufficient demand for very hot, pure, and low magnesia lime, there is no doubt but what there will be those in Ohio who will furnish it.

The dolomite limes have probably received wider distribution than the limes higher in calcium oxide, on account of their great purity and desirability for use in the manufacture of wood pulp for paper by the sulphite process. For this purpose, large quantities have been shipped

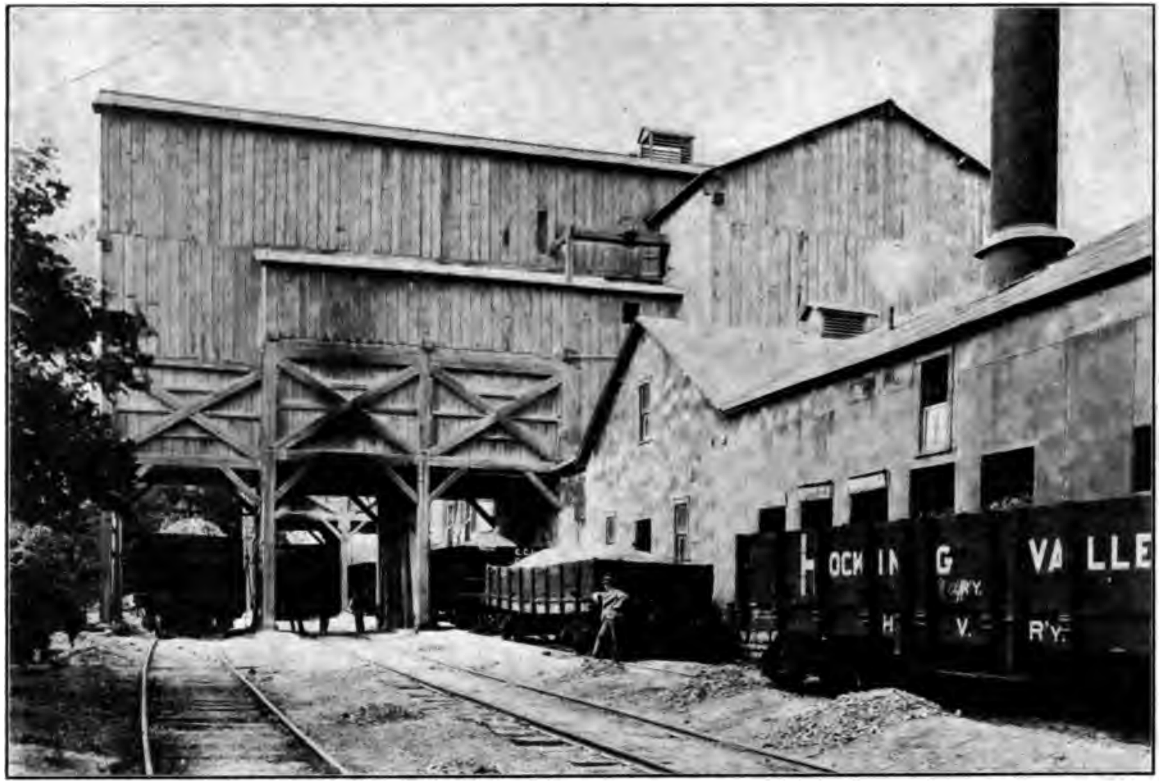

Figure 14.—Casparis quarries, Columbus, O. The crushing plant, showing the outgoing or delivery side, where the railroad cars are loaded with the various grades of products.

to Canada, Maine, New York, North and South Carolina, Georgia, Washington and Oregon, and Colorado, notwithstanding that in many cases they had to pay a freight charge of twenty-five cents or more per hundred pounds. They have done this when there were dolomite limes being made much nearer the pulp-mills. The pulp-makers have felt that the purity and quality of the product justified the additional cost.

The high-calcium or hotter limes have been shipped great distances for chemical purposes. They are much used and found very desirable by sugar factories, acetic acid and calcium acetate plants, as well as in the manufacture of soda ash.

As pointed out elsewhere, the lime industry is now located in centers, where the stone is of good quality and transportation facilities are good. It is not to be concluded that the industry is limited to these sites, for lime of excellent quality may be made in many hundreds of localities which chance has not yet provided with an outlet or local demand.

Without attempting to discuss at this point the technology of the lime industry, it should be said that the term lime is a very loosely defined term, having no accurately fixed meaning in common practice. It may be defined as the residue of a limestone, left when all volatile matters have been expelled by heat. Calcium oxide is the active chemical ingredient of lime, but the amount of this oxide which a calcined stone must have to be classed as lime is not fixed by custom or statute. By general consent, the term limestone would be restricted to rocks containing sufficient carbonate of calcium to make a caustic product after burning, which product would either slack on exposure to water, or by hydraulic changes harden into a cement. The carbonate of calcium or calcite may be replaced in whole or in part by another mineral, dolomite, which is the double carbonate of calcium and magnesium, containing fifty-six parts of calcium carbonate and forty-four of magnesium carbonate. Dolomite is a real mineral, having a definite crystal form, fixed composition, and properties different from either calcite or magnesite.

A dolomite limestone is made up of crystals of this mineral, mixed with sandy grains, clay, oxide of iron and alumina, etc., just exactly like the pure limestones, of which calcite is the body mineral.

Other limestones are common, in which the proportions of carbonates of calcium and magnesium do not represent either calcite or dolomite, but apparently represent a mixture of those minerals. In such cases the proportions of magnesium carbonate may range from 0 to 44 per cent. There are a few analyses that indicate that the carbonate of magnesia in some limestones is higher than the dolomite ratio. Such cases must be considered as mixtures of dolomite and magnesite, unless an error was made in the analysis. In many limestones, there seems little evidence of the existence of crystalline minerals, either calcite or

dolomite or magnesite, but the stone consists of an apparently amorphous paste of fine precipitated carbonates, indistinguishable by the eye or by any means except chemical analysis.

Since all these various stones are called limestones in the trade, and in general scientific literature, it follows that their products on calcination are all limes. Unless specification is made in an order for lime, the customer may be served with any of the various kinds.

Classification of Limes.—Owing to the difference between the heat developed by the hydration of calcium oxide and magnesium oxide, Ohio limes are divided into two classes: hot, gray or high-calcium limes, and cool, white, or dolomite limes. There should be a third grade recognized, since it is actually represented in the trade, i. e., one which is intermediate between the two extremes. This might be classed as moderately-hot, or magnesian lime, to separate it from the dolomite limes, which contain much more magnesia than this intermediate class. The dolomite limes are today frequently called magnesian limes, as distinguishing them from the hot or high-calcium product.

Distribution of the Lime Industry.—The hot limes of Ohio are represented by the limes burned at Cincinnati from the Hudson River group, which is highly calcareous; the lime burned at Marble Cliff near Columbus; and that burned at Scioto, west of Delaware. At both of the latter places, limestone from the Corniferous horizon is burned. The lime produced is almost white. The Clinton formation, at Piqua, Miami county, also produces a hot lime, though no large amount of it is burnt.

The moderately-hot limes come, with one exception, from the Corniferous. The principal localities are Marion county, Marblehead, Sandusky, and Kelley's Island. The exception is New Paris, where the lower Niagara stone is burned.

The cool limes are found as the product of all lime kilns on the Lower Helderberg and Niagara horizons.

The centers of production of lime are Marion and vicinity; Marblehead, Kelley's Island and Sandusky, including eastern Ottawa and Erie counties; the dolomite interests in the northwestern portion of the state are covered mainly by the plants located on the Niagara in Sandusky, Seneca, Ottawa, and Wood counties; Springfield, Clark county, and vicinity. The two first named are on the Corniferous, while the two latter are mainly located on the Niagara formation.

Although so large a portion of Ohio is covered with limestones of the highest quality for lime-burning, usually accessible at numerous points in every county, the fact remains that the lime industry is becoming less and less common over the country at large and more and more confined to the few foci named above.

It is probable that the four prime factors in the localizing of lime production were:

First: Proximity to good markets or ready access to large territory which has no limestone adapted to the manufacture of a high-grade lime.

Second: Purity of the limestone—i. e., freedom from discoloring substances.

Third: The thin covering of earth over the stone, by which the cost of stripping is kept low.

Fourth: The availability of labor of good quality at a reasonable price. This is a more important factor than it is generally considered to be. It is difficult to keep good men at work for any length of time in isolated localities, especially if the plant be a small one, only employing a few men. In such cases, it is usually necessary not only to pay the superintendent and foreman greater salaries to induce them to remain, but common labor, except in rare cases, is higher, and the workmen are more unreliable and more independent as to the amount of time they will devote to work. Of course, there are occasions where other factors will more than counterbalance these disadvantages. Thus, while at an early date each neighborhood produced its own lime, burning it in small intermittent kilns, or even in loose heaps on the ground, the trade has gradually concentrated at certain points under the influence of the above factors, until now we find the industry very strong and influential as a wealth producer in some counties, while other adjoining counties possessing the same mineral endowment are unable to get a start.

Effect of Centralization.—This centralization has had a salutary effect on the industry in Ohio. It has been the main factor in bringing the industry from one of local importance to one of interstate and even national importance. It has materially increased the commercial importance of the state as a whole, bringing in large sums of money from other states which are using this Ohio product. It has fostered the organization of large and aggressive companies, which have bought up and operated many of the small plants as one unit. It has fostered the united efforts of all Ohio lime manufacturers in a common cause, the widening of the market for Ohio limes and prosecuting the search for new uses for them, as well as for improvements in their manufacture. At one time in the history of the Ohio lime trade, the very existence of the high-calcium interests was threatened by the very rapid increase in the use of portland cement in all brick and masonry construction, and the wide use of concrete. Brick and masonry construction was the main use for the strong limes at that time. While there is no doubt that the increased use of cement did check the growth of the plants manufacturing the higher calcium limes, they were not permanently affected and today they are producing approximately as much as formerly. They have found new avenues through which they could dispose of that part of their produce which was not taken up by the large increase in building operations, although the percentage of their product entering construction work is gradually decreasing in favor of an increased use of portland cement.

Recent History of the Industry in Ohio.—In 1898, the dolomite or white lime industry of the state was at a low ebb. It looked as if this phase of the industry was to be confined to burning in the small way for local consumption only. The factors which brought about this condition of affairs were: *First:* The well organized and aggressive attitude of the high-calcium lime manufacturers, who gradually forced themselves into markets formerly controlled by dolomite lime interests. *Second:* The lack of organized and consistent effort on the part of the dolomite lime manufacturers. *Third:* The dolomite lime industry consisted of a large number of small operators each running only a few kilns, which were not of the most economical type. The other lime interests of the state were confined to a few large and well equipped plants. *Fourth:* About this time the hard wall plasters were making serious encroachments on the trade for interior wall finish, which had been in former years largely supplied by the dolomite lime manufacturers. At this time hydrated lime was almost an unknown commodity, and the hard wall plaster manufacturer used but little lime in his mixture.

This same date, however, marks the beginning of a period of progressive and rapid development for the dolomite lime industry of the state. Some of the old manufacturers realized the existing conditions, and put more money into their plants, and made extensive improvements, and put more energy into their business policy. Others who had confidence in the quality of dolomite lime and its products, and who realized its possibilities, bought up good locations and built modern plants. Both the old and the new manufacturers took up an energetic and aggressive policy and eventually joined hands in a common course —i. e., the promotion of the use of dolomite limes, as well as the improvement of the quality of the product wherever possible to do so. The result was that the number of operating kilns making dolomite lime has increased almost one hundred per cent. since that date. On the other hand, while there have been several new and modern plants built on the high-calcium belt, there has been no material increase in this period in the number of operative kilns. While there is today a larger number of kilns in the high-calcium belt that could be put in commission on short notice, than there is in the dolomite field, the total annual production is slightly in favor of the dolomite limes. There are several reasons for this condition of affairs. *First:* The dolomite limes being less energetic in their slaking and less susceptible to atmospheric influences can be stored longer without material deterioration than the limes higher in calcium oxide. This permits the dolomite lime manufacturer to keep his kilns in more continuous operation than can his competitor who is making a hotter lime. *Second:* The great bulk of hydrated lime produced in the state comes from the dolomite horizon, and this product can be stored indefinitely or until such time as market conditions demand its movement. *Third:* The majority of the agricultural lime shipped is from the dolomite centers, and for this purpose the lime may be held in storage for a longer period than when it is to be used in construction work, since the presence of air slaked lime is no serious detriment to its use in the neutralization of soil acids, and the release of plant foods from the various fertilizers and soils, many of which are sparingly soluble in the absence of some catalytic or carrying agent, such as calcium and magnesium oxides. An Eastern lime manufacturer, burning dolomite, who has a large agricultural trade, is building a large steel tank which will hold many car loads of ground lime, so that he may be able to keep his kilns in continuous fire during the winter, and be ready to meet the heavy spring demand, which at that period is far in excess of his capacity. There will not be any great amount of air slaking, as a thin coat of air, slaked or hydrated lime on the surface will protect the main body of lime-making it almost air tight. From the above statements it is evident why the continuous operation of dolomite lime kilns is not interfered with as materially by changes in market demands, as in the high-calcium plants. This means that the hot-lime manufacturer, in order to meet the emergencies, must possess greater kiln capacity than he can keep in constant operation.

The Kelley Island Lime and Transport Company is the largest single producer of lime within the state. They own about seventy-four kilns in the state, and six or eight more at Duluth, Minn. The latter are supplied by stone shipped by water from Kelley's Island and Marblehead. It is probably safe to state, however, that their annual output does not exceed sixty per cent. of the total capacity represented by these kilns. Their properties located at Kelley's Island, Marblehead and Sandusky are very favorably situated with reference to large and good markets, being in easy reach by water transportation of such centers of population as Detroit, Toledo, Cleveland and Buffalo. This firm maintains a number of large warehouses in Cleveland, from which they distribute a general line of builders' supplies as well as lime and cement. They own and operate a number of large boats for the handling of their output, as well as a railroad on Marblehead which connects with the Lake Shore road. It is a significant fact that this firm, which up to this time has produced nothing but high-calcium lime, has within the last year purchased the sixteen kiln plant and property of the Toledo White Lime Company, at Clay Center, which is a producer of dolomite lime. It is probable that this firm realized that if they wished to maintain their former supremacy in the lime market, they must have at least one plant producing good dolomite lime. There is no doubt but that this newly acquired property will be put in the best of condition, and operated mainly for the production of a hydrated lime. Lime has been hydrated at Marblehead for some time, but the product has not been as well received as the hydrated dolomite lime, which gave a whiter mortar.

The Marion district has a much larger territory available, but not so many large centers of population in easy reach, to stimulate the production of lime. While it does not have cheap water transportation, it has excellent railroad facilities for shipment, being tapped by a number of good systems which make large territory available for direct shipments. The dolomite section of northwestern Ohio is close to Toledo, and has ready access to Cleveland and Pittsburg and the territory to the west and northwest in the adjoining states of Michigan, Indiana, and Illinois, but is not confined to or dependent on these points, since this section is putting its lime output into more states than is any other Ohio lime center.

The Clark and Highland county center supplies southern Ohio, Springfield, Dayton, Cincinnati, and such trade in southern Indiana and Kentucky as demands a very white lime.

Lime Production.—The lime production of the various larger districts is about as follows:

Table XI—Lime Production by Districts.

	Bushels of 70 pounds per annum.
Kelley's Island, Marblehead and Sandusky	2,270,000
Marion county and vicinity	1,836,000
The northwestern Ohio dolomite center	3,317,000
Piqua, New Paris, Cincinnati	250,000
Clark and Highland and vicinity, the southwestern Ohio dolomite center	1,147,000
Total	8,820,000
Lime above 65% calcium oxide	4,356,000
Dolomite lime or that below 65% calcium oxide	4,464,000

The production by formations is approximately as follows:

Table XII—Lime Production by Formations.

Corniferous	4,106,000
Upper Niagara	3,205,000
Lower Helderberg, or Waterlime	1,259,000
Lower Niagara	72,000
Clinton	72,000
Hudson River	70,000
Total	8,784,000

The production of lime in Ohio for the last few years has hung around 8,500,000 bushels of seventy pounds each, per annum. The capacity for production within the state could very quickly and easily be increased by twenty-five to thirty per cent. more than this, by making repairs on kilns now idle, and keeping them in something like continuous commission.

From the above tables, it is seen that the production of the dolomite lime has a slight lead over the high-calcium product. This was probably not the case five years ago.

An Ohio manufacturer who has been devoting considerable time and energy in procuring information of this sort, made the following estimate of the total tonnage of lime and lime products for the state for 1905:

Table XIII—Total Lime Production of Ohio.

	Tons of 2,000 pounds each.
Lump lime (bulk and barreled) three-quarters of which was high-calcium lime	58,000
Lime for agricultural purposes, mainly dolomite	53,000
Ground lime, mainly dolomite	46,000
Hydrated lime, mainly dolomite	65,000
Total	222,000

This estimate is undoubtedly very close for agricultural ground and hydrated lime, as the person in question is in a position to know what is being done in those lines, but this estimate seems to the writer to be far too low for bulk lime. His figure for bulk lime should be increased by about 62,000 tons to represent true conditions in Ohio, thus making the total tonnage of lime in its various forms, 284,000 tons. The total tonnage of Ohio might then on this basis be approximately proportioned as follows:

Table XIV—Classification of Estimated Lime Production, by Percentages.

	Percentage of total tonnage.
Lump lime	42.3
Lime for agricultural purposes	18.6
Ground lime	16.2
Hydrated lime	22.9
Total	100.0

While the estimates on which the above is based are probably a little low, due to the ignoring of a number of small and isolated plants, which are not kept in continuous operation, the true relation of the amounts of the various products to each other is exceptionally close to the above figures.

Another manufacturer who is not producing hydrated lime, but is known as a strong factor in the agricultural trade, as well as in the paper and glass trade, gave the following as representing the distribution of his product for 1905 as shown by his books:

Table XV—Classification of Estimated Lime Production, by Percentages.

	Per cent. of total tonnage.
Bulk lime	25.0
Barreled lime (some of which was ground)	40.0
Lime for agricultural purposes (crushed only)	25.0
Ground lime (reduced to 80 mesh) for the glass trade and for spraying	10.0
Total	100.0

New Forms of Lime.—The ground lime sold for building purposes was not included in the ten per cent. given. The demand for ground lime in the building trades is considerable and constantly growing. It keeps well in barrels and slakes more rapidly and leaves less waste material when the putty is screened for use on the walls, and when used unscreened for mortar, there are no stones or large particles to interfere with the rapid laying of brick or stone. The price of ground lime is almost the same as that of lump lime, so this offers no drawback to its increased use.

In the last ten years, we see a great change in the trade demand or manner in which lime is put on the market. Ten years ago, crushed and ground lime was but little known and hydrated lime was not on the market, at least not as a well recognized commodity, and lump lime constituted ninety five per cent. of the output. Today, considerably less than fifty per cent. of the lime leaves the plant in the lump or untreated form; in fact, over sixty per cent. of the lime manufactured in Ohio does not go on the market in exactly the condition in which it was drawn from the kiln.

Ohio producers were the first to grind lime for the trade. If not the first, they were among the pioneers in the introduction of crushed lime for agricultural purposes. It was first considered as a fertilizer, and is still so called by many farmers. The Ohio lime producer with characteristic energy in his efforts to gather all useful information for his customers soon found out that it could not be classed exactly as a fertilizer, but must be considered rather as a liberator of plant food, instead of being the food itself. In other words, he found out from agricultural chemists that lime acted as a medicine for sick soils, and as a stimulant to the action of fertilizing agents held in the soil, or bodies deposited on or within the soil, which were practically inert without the presence of a neutralizing, carrying or transposing element such as calcium and magnesium in their various compounds. The oxide or quicklime naturally was found to be the most active agent for this purpose. The Ohio manufacturer has done a great deal in the way of disseminating information as to the office which lime performs in the growth of plant life. He has tried to show what soils need lime, when they need it, and how much should be used. He has distributed the results obtained by other investigators as well as his own experiments in this direction. As a result, lime for agricultural purposes is today an important factor in the lime production of the state.

Ohio is undoubtedly the pioneer state in the production of hydrated lime in a merchantable form, and in commercial quantities. It is very probable that the first hydrated lime, made to be sold as such, was produced in Ohio. From a very modest start, about ten years ago, the hydrated lime industry has grown steadily until today it stands as one of the most important of the products of the state's mineral resources. Ohio is probably producing at least twenty-five per cent. of all the hydrated lime manufactured in the United States. Hydrated lime is nothing more than slaked lime in a dry powdered form, which has had all the unslaked cores and coarse impurities removed. It is put on the market in sacks, either paper or burlap, and can be used for nearly all purposes for which quicklime proves desirable.

The Marketing of Ohio Lime.—Ohio limes are sold by weight. The prices named below are for a hundred weight or ton although quotations frequently are given by the bushel or barrel. For lump lime, seventy pounds net is considered a bushel, and one hundred and eighty-five pounds net a barrel. When lime is shipped in bulk by the carload, it is usually sold by the ton. When it is shipped in barrels, the cost of the barrel and the cost of the labor of putting the lime into the barrels, and heading it up, is added to that of bulk lime. In 1905, the cost of barrels ready to fill was about twenty-one cents each. Barrels of ordinary size are used, with fifteen and one-half to sixteen and one-half inch heads, and twenty-eight and one-half inch staves. An empty barrel weighs fifteen to sixteen pounds. A barrel will hold about four hundred pounds of ground lime, or two hundred and fifty to three hundred pounds of hydrated lime. Very little ground lime goes into barrels, and practically no hydrated lime is moved in this type of package. The following prices are a fair representation of market conditions in 1905. Of course there were fluctuations up and down, governed by the law of supply and demand. Variations in price were also made in some instances to meet competition from some points, or to help out on heavy freight charges for long shipments.

Table XVI—Prices, F. O. B. Cars at Plant.

	Per ton of 2,000 pounds.
Lump lime in bulk	$3.25 to $3.75
Lump lime in barrels	5.50 to 6.00
Lime for agricultural purposes in bulk	3.50 to 4.00
Ground lime in bulk	3.40 to 4.00
Hydrated lime in bulk	4.75 to 5.25
Hydrated lime in 40-pound paper sacks	5.50 to 6.00
Hydrated lime in 100-pound burlap bags*	5.75 to 6.25

Market conditions are good in the lime industry at the present time, and have been so for several years. The demand for lime has been large, but the supply has been up to the demand. Prices have been reasonable, yet high enough to give the lime manufacturers a fair profit. The feeling among various manufacturers is very friendly, and it is likely there will be no serious price wars in the near future.

Cost of Production.—Through the courtesy of W. S. Sutliff, of the Seneca White Lime Company of Fostoria, the costs of production at that plant as taken from the company's books for the first eleven months of 1905 are given. This is a well equipped and modern plant, under good management. If this plant could not make a good profit, the small and poorly equipped manufacturer would surely be hard pushed to do so. This plant will be described in detail later. The fuel used is natural gas.

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*Burlap bags returnable at 10 cents each.

Table XVII—Cost of Production.

	Cost per barrel of 185 pounds.
Fuel	7.45 cents
Labor for all purposes	13.70 cents
Fixed charges	4.00 cents
Barrel	21.00 cents
Total	46.15 cents

The feed for teams, cost of explosives, and allowances for repairs were not included in Mr. Sutliff's analysis; it may be seen that the lime business of the state is being handled on a very close margin. If anything, the lime manufacturer is not getting enough for his product, since when the omitted costs are added in the above schedule, the margin for profit is very small. Market conditions in the different cities vary markedly as to the distribution of lime for various purposes, as is indicated by the following statements with reference to the sale of lime made by the largest dealers in builders' supplies in three of the large cities of the state. The first of these dealers says:

"We believe that notwithstanding the fact that we have hard wall plaster plants in our city, that fully seventy-five per cent. of the interior walls in this city are being put in with lime mortar, and that over half the lime sold here is used in that way."

A second dealer says: "As far as our business is concerned, we sell about one-half of the lime which we purchase for plastering purposes, and the other half for brick laying. Years ago, before hard wall plaster came into the market, we sold bulk lime in a different proportion; about two-thirds of the lime was then sold for plastering and one-third for brick laying. This, naturally, refers to our market only.

"While a good deal of hard wall plaster is now sold for plastering, some of our best contractors just now use ground or hydrate lime for plastering also, and we are now furnishing a few large jobs on these lines."

The third dealer says: "About ten per cent. of the lime handled by us is used for interior walls, as ninety-five per cent. of the plastering in this district is done with patent plasters. The other ninety per cent. of our lime is used for laying brick, stone, and work of this character, but I wish to state that cement is replacing lime for this class of work, as our lime trade is but twenty per cent, of what it was three or four years ago."

HYDRATED LIME.

Within the last few years a new product has been put on the market by Ohio manufacturers, known to the trade under various names, such as "Rock Wall Finish," "White Rock Finish," 'New Process Lime," "Standard Rock Wall Finish," "Limona," etc. This new product is hydrated lime, or quicklime which has been slaked.

The slaking may be carried on to a point where the resultant material is a wet paste, or putty. In this case, the putty has to be dried and ground to a fine powder. Or, by adding just water enough to slake the lime, the heat generated is sufficient to dry off the excess water, and leave the product as a dry powder. In either case, unslaked lumps have to be removed by screening.

If the lime were pure, and hydration *complete*, this would mean, theoretically, that each one hundred pounds of lime treated would be increased in weight by this hydration by from thirty-two to thirty-seven pounds, depending on the composition of the lime; magnesian or dolomite lime, theoretically, would take the greater increase in weight. In other words, for each one hundred pounds of quicklime, we should expect from theory to get one hundred and thirty-two to one hundred and thirty-seven pounds of hydrate.

But the lime is never entirely pure, nor is hydration often entirely complete. What is actually obtained in practice with dolomite lime is an increase in weight of eighteen to twenty-five pounds per hundred pounds of quicklime treated, depending on the lime and the treatment which it receives. With the high-calcium limes it is possible to introduce more water by mechanical slaking. For this type of limes, each one hundred pounds of quicklime take up from twenty-three to thirty pounds of water.

Hydrated lime, when ready for the market, is a powder of almost impalpable fineness, snow white and very beautiful to look upon. It is put up in neat, easily-handled packages. It is shipped in paper bags of forty pounds each or in burlap sacks of one hundred pounds each. It does not change materially, if at all, with age, and can be stored for long periods of time in the original package, if kept in a dry place. It answers essentially all the requirements for all purposes for which freshly-slaked quicklime is used. Hydrated lime has uses, such as in hard wall plaster, for which quicklime is undesirable.

The usual method of preparation is to crush the lump lime, and add with mechanical agitation sufficient water to slake the lime, and leave a slightly moist hot powder, which by the time it is cooled, with further agitation, becomes a dry powder. The coarse impurities are separated from the fine hydrate by bolting or by air separation. In some cases, the hydrate is ground before separation.

Hydrated Lime for Agricultural Purposes.—Lime for use on the soil, with or without the addition of fertilizer, and for the spraying of plants and trees, has reached such importance to the Ohio manufacturer, that it deserves more than passing mention as to the offices it performs in promoting plant life. We therefore quote the following from Bulletin No. 157, Ohio Agricultural Experiment Station, by Chas. E. Thorne, published in March, 1905.

"Lime is absolutely indispensable to the growth of plants, yet it is required in comparatively small amounts. The cereal crops, for example, take from the soil several times as much potash as lime, although soils usually contain as much lime as potash.

"Lime, however, performs other functions in the soil than the supplying of plant food. One of the most important of these is the neutralizing of acidity. Acid soils are as yet unknown over many parts of Ohio; but in other sections, especially in the eastern half of the state, where the soil has largely been formed from the decomposition of andstones and shales, this condition is becoming increasingly prevalent, and is manifested by the constantly enlarging areas in which clover is displaced by sorrel.

"A partial explanation of the fact that acid soils do not furnish the best conditions for crop production is suggested by the investigations by Warington and others on nitrification. These researches have shown that this process is dependent upon the presence in the soil of a salifiable base; that is, of a base with which the nitric acid resulting from the nitrifying processes may unite, forming a salt. For such a base, lime is the most suitable material, because of its comparative cheapness and of its importance as a constituent of living tissue. This means that some excess of available lime in the soil is necessary, over and above the bare needs of the growing crop for tissue building. On the other hand, these investigators have shown that an excessive application of quicklime to the soil may exert an exactly contrary effect, stopping the work of nitrification until the quicklime is converted into the less active form of carbonate.

"Another function performed by lime is the liberation of plant food from compounds in the soil. If a little freshly burned lime be mixed with strong manure, such as hen manure, or fresh stable manure, an odor of ammonia will become apparent. This means that the lime is entering into chemical union with certain constituents of the manure, and in doing so is liberating others, which pass off in the form of ammonia gas. If such lime be mixed with the soil, a similar action will take place; the lime will unite with the decaying vegetation of the soil, liberating nitrogen in the form of ammonia. If a crop be growing upon the soil, it may absorb a part of the escaping ammonia, and a larger yield will result; but this larger yield is produced at the expense of the soil stores of plant food, and if these stores are not maintained by liberal manuring, or fertilizing, the soil will eventually fail to respond to lime, because all the material in it upon which lime can act has been destroyed. leaving the soil poorer than if no lime had been used.

"Not only does lime liberate nitrogen, but it may also act upon the potassium of the soil, converting it from insoluble combinations into those available as plant food. To a certain extent this may be a useful function, in the case of both nitrogen and potassium, but it may be carried to such excess by heavy and continuous liming that the plant food will be liberated more rapidly than the crops can make use of it and loss will occur from leaching.

"A third function of lime is the amelioration of the texture of the soil. When heavy, plastic clay is wet, pressed into a cake and then dried, it becomes almost brick-like in texture; but if a small portion of quicklime be incorporated with the clay before manipulation, it will crumble easily between the fingers after drying. For this purpose lime may be very usefully employed on many of the more refractory clay soils, using it at the rate of several tons per acre. Clays thus treated will become much more friable, will respond more readily to cultivation and manuring, and will not pack so readily under rain. The effect of such an application of lime will last for a number of years. It will be easily understood that the opening of the soil by a dressing of lime will facilitate the action of air, rain and other agencies by which the plant food of the soil is made available to crops. Loose sandy soils may also be improved by liming, the lime rendering them more compact and more retentive of moisture.

"For more than a century, British and European farmers have used lime on the soil, and the effect of lime has been summarized in the two following proverbs:

" 'Lime enriches the father, but impoverishes the son.'

" 'Lime and lime without manure,
Will make both farm and farmer poor.'

"This does not mean that lime should never be used, nor that lime should be mixed with manure; but that lime and manure should follow each other in an intelligently ordered succession."

That lime has a desirable effect on acid and clayey soils there can be no doubt, no matter what the avenue through which it accomplishes the results. It acts as a carrying agent, and aids in the transformation of non-available but desirable constituents in the compounds contained in the soils and fertilizers, into compounds which render the desirable elements available for further transformation into plant life by nature's agents, the sun, and the minute bacterial organisms.

Such investigators as have made comparative tests of the use of quicklime and hydrated lime report as a result of their observations that there is no material difference in the results obtained. There is in the trade, however, a strong preference for the quicklime, for two probable reasons: *First:* The physical character of the crushed quicklime is such that the distribution is more readily accomplished. *Second:* The price paid for each unit of the active agent, the calcium or magnesium oxide, is less when quicklime is used than when the hydrate is applied. However, a large amount of the tailings from hydrating plants has been used for this purpose and with apparent satisfaction. These tailings are probably sold at a much lower price than the hydrate or quicklime.*

Hydrated Lime in Mortars.—There are several uses for hydrated lime, which seem to have received but slight attention from the Ohio lime manufacturer. While the addition of hydrated lime to portland cement mortars probably does decrease their ultimate strength, it also adds better working qualities under the trowel, and greater density and better water-proofing qualities to the hardened mortar, and at some places hydrated lime is much used for this purpose, as well as in concrete mixtures, both for hollow block and monolithic structures.

The following table, abstracted from a paper presented to the National Lime Manufacturers' Association in February, 1905, by E. W. Lazell, will give some idea as to the behavior of a high-calcium lime paste and portland cement.

Table XVIII—Tensile Strength in Pounds per Square Inch.†

Number	Composition of mixture.	7 days.	28 days.	3 months.	6 months.	9 months.	1 year
1	1 cement, 2 sand, 0.25 part lime paste.....	190	312	340	750	785	585
2	1 cement, 3 sand, 0.50 part lime paste.....	160	265	360	560	530	540
3	1 cement, 4 sand, 0.75 parts lime paste....	140	185	270	455	520	445
4	1 cement, 5 sand, 1 part lime paste........	55	80	135	265	300	280
5	1 cement, 6 sand, 1.25 part lime paste.....	50	25	62	260	295	310
6	1 cement, 8 sand, 1.5 part lime paste......	50	75	110	265	268	262
7	1 cement, 10 sand, 2 part lime paste	30	58	122	145	190	185

It was thought by the author of this paper that the sand used in this test was crushed quartz so mixed and graded as to give thirty-five per cent. voids.

With reference to these results, Mr. Lazell says in substance as follows: "Numbers one and two did not show as good a strength as

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*More complete and detailed information on the use of lime in land fertilization can be obtained in Storer on *Agriculture*, three volumes; *The Fertility of the Land*, by Roberts; *Fertilizers*, by Voorhees; the reports and bulletins of the states of Rhode Island and Pennsylvania, any of which, that are still in print, can be obtained by writing to A. A. Brigham, Ph. D., Agricultural Experiment Station, Kingston, R. I., and to Dr. Wm. Frear, Ph. D., Pennsylvania Experiment Station, at State college, Center county, Pa.; and the reports and bulletins of the Ohio Agricultural Experiment Station, Prof. C. E. Thorne, director, Wooster, Ohio.

†These figures were taken from a rather indistinct curve sheet, so they may vary from the actual results by a few pounds.

sand-cement mixtures of the same proportions would have done, but with number three, when four parts sand, one cement and 0.75 parts lime paste was used, the strength obtained exceeded that for a similar mixture of sand and cement alone. This is explained by the fact that in the first two cases the cement was more than sufficient to fill the voids, while in the latter case the cement was not sufficient to do this, and the lime therefore gave added strength by filling them."

From the above we might then infer that for sands low in percentage of voids, used with cements or for mixtures of sand and portland cement very rich in cement, lime would be a detriment to its strength, but for sands high in percentage of voids, or mixtures lean in portland cement, lime would be a decided advantage and add strength to the mortar instead of detracting from it.

The behavior of dry hydrated dolomite lime is shown from the following table, taken from the Engineering Record, December 12, 1903:

Table XIX—Tensile Strength in Pounds Per Square Inch.

Number.	Composition of Mixture.	Age of briquettes.			
		7 days.	28 days.	3 months	1 year
1	1 cement, 2 sand, 1.5 hydrated lime......	88	135	148	245
2	1 cement, 2 sand, 1.25 hydrated lime.....	100	145	155	228
3	1 cement, 2 sand, 1.00 hydrated lime.....	138	170	175	225
4	1 cement, 2 sand, 0.75 hydrated lime.....	120	175	218	290
5	1 cement, 2 sand, 0.50 hydrated lime.....	130	178	182	280

All of these results show a gradual increase in strength with age, which indicates that no undesirable features are introduced with the addition of dolomite limes in the dry hydrated form. It must also be observed that the results so far as lime is concerned cannot be compared to the preceeding table.

Of more importance, however, is the fact that hydrated lime adds to the strength of mortars made from natural-rock or roman cements, when added to it in amounts from five to thirty per cent. and even more. It seems to supply something that is lacking in these cements; it acts as a stimulant, as it were. Much can be done in pushing the sale of lime for this purpose. The use of lime with roman cements may be the means of supporting what for several years has been a waning industry in this country. The following results obtained by Messrs. H. B. Nichols and Ross E. Hamilton, while students in the Department of

Civil Engineering at Ohio State University, clearly indicates the stimulating effect of lime on roman cements. Mixtures of Louisville cement and varying amounts of a fat slaked lime or lime putty were made and sand incorporated. The ratio of two of sand to one of cement or cement and lime mixture was maintained throughout. It would have been easier to get a uniform mixture had they used dry hydrated lime.

Table XX—Work of Hamilton & Nichols.

Composition of mixtures.			Tensile strength in pounds per square after 26 weeks.
Louisville cement. Parts.	Fat lime. Parts.	Sand.	
1.00	0.00	2.00	292
0.96	0.04	2.00	335
0.92	0.08	2.00	325
0.90	0.10	2.00	325
0.85	0.15	2.00	322
0.80	0.20	2.00	357
0.75	0.25	2.00	304
0.70	0.30	2.00	335
0.50	0.50	2.00	170

From the foregoing, we might conclude that lime up to thirty per cent. of the cement used would be desirable, but that as much as fifty per cent. was a detriment.

Had dry hydrated lime been ground with the cement, more uniform and probably better results would have been obtained.

The following results obtained by Professor A. V. Bleininger, Bulletin 3, Fourth Series, Geological Survey of Ohio, p. 191, illustrate the very desirable effects of grinding dry hydrated lime and roman cements.

Table XXI—Work of Bleininger.

Mixtures.	Tensile strength in pounds per square inch.			Remarks.
	1	2	3	
100 parts roman cement 0 parts lime 100 parts sand	...	135	100	No. 1 briquette checked. No result.
95 parts roman cement 5 parts hydrated lime 100 parts sand	230	200	270	

For this experiment, the cement rock was calcined and a portion of it ground. To the balance, five per cent. of dry hydrated lime was added, and this mixture was also ground. In making these tests the same amount of the resultant powder was used in each case, that is, the lime hydrate was not an addition to the cement in the mixture, but displaced just that much cement. The briquettes were twenty-eight days old when tested. In this case, the increase in strength due to the addition of lime is very remarkable.

This outlet or use for hydrated lime is well worthy of attention from the manufacturers. They should consult with the roman cement manufacturers, and induce them to use hydrated lime, since the best results will be obtained by grinding the hydrated lime with the rock or roman cement, which can readily be done by introducing hydrated lime in proper proportions before the final grinding is given the cement in its process of manufacture.

By the use of considerable quantities of hydrated lime, ground with a small amount of gypsum plaster, and a strong proportion of a light colored roman cement, a wall plaster or finish could be made which would be slow setting, but in time acquire great hardness and beauty of surface.

Professor Bleininger* found that sound white roman cements could be prepared artificially from either calcareous or dolomite limestones very low in iron, and mixtures of kaolin or kaolin and potter's flint burned at low temperatures. The dolomite mixtures showed much the greater strength, as well as greater range of permissible composition.

The following cement formulæ were found to give the best results:

A (2.5 CaO) SiO_2, CaO, Al_2O_3.

B and C (2.5 CaMgO), SiO_2, (CaMgO), Al_2O_3.

These cements analyzed as follows:

Table XXII—Composition of Bleininger's Cements.

Designation of cement.	Silica SiO_2	Alumina Al_2O_3	Lime CaO	Magnesia MgO.
A	27.41	8.77	62.88	.....
B	23.38	20.18	33.80	22.50
C	28.60	9.57	37.09	24.79

Cement A was a mixture of pure high-calcium limestone, kaolin and flint.

The best burning temperature for cement A was 1000° C.

Cement B was a mixture of a pure dolomite stone and kaolin.

Cement C was a mixture of a pure dolomite stone, kaolin and flint.

The best burning temperature for cements B and C was 950° C.

The tensile strengths obtained on briquettes twenty-eight days old, made from 1 cement and 1 sand, were as follows:

	Pounds per square inch.
Cement A	225
Cement B	320
Cement C	235

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*Bulletin 8, Series 4, Geological Survey of Ohio, pp. 181-185.

While the ordinary limekiln would hardly be the most economical way of producing these cements, yet it could be used. These statements should be suggestive to the lime producers, especially the larger ones, since it would give them a means of regaining the trade lost in recent years by the encroachments of the manufacturer of patent or hard wall plasters. He could manufacture his own cement, and hydrated lime, grinding them together, and then sell this prepared plaster either in the neat form, or mixed with hair or wood fibre as desired. The commercial feasibility of this process is certainly worthy of investigation by the lime producers.

Hydrated Lime in Cold-water Paints.—The use of lime in the manufacture of cold-water paints should not be overlooked by the producer of hydrated lime. Cold water paints are much used. The largest single constituent in these paints is hydrated lime. They are made by grinding with hydrated lime, first, the coloring matter to give the tints desired, and second, five to ten per cent. of casein, to give the necessary adhesiveness. Many attempts have been made to find a satisfactory substitute for casein for this purpose, but so far without avail. Glue in almost the same proportion works very well, but the paint must be applied hot, which is a great disadvantage, and takes it out of the class of cold water paints. In the early use of cold water paints, sugar, molasses, or skimmed milk and many other agents were used to improve the adhering quality of these paints. When it was found that skimmed milk gave the most desirable results, it was at once suggested that it was due to casein and such proved to be the case. Patents have been extant for many years on the use of casein in this connection, but most of them have expired, and those running today stand much in the light of renewals of old ideas, and are perhaps not on any too firm a footing, if attacked as to their validity.

Calcimines.—Calcimines and prepared whitewashes might receive more attention from Ohio lime manufacturers. The following mixture keeps well in packages and gives good results:

	Parts.
Hydrated lime	92
Calcium chloride	3
Alum	4
Sulphate of zinc	1

Sorel Cements.—Another means of promoting a still more extensive use of dolomite lime has been suggested by Thomas W. Cappon. He suggests developing the sorel cement reaction of the magnesia in these limes as a means of producing a cement or plaster, by the introduction of chlorine in some very cheap form, such as by using the residual liquors from salt works. So far this idea has received no commercial development of consequence, nor have the weather resisting qualities of the product been definitely proven. While time may show some inherent faults which will prove a serious obstacle to its general use, the idea has sufficient promise today to be well worthy of the consideration of the manufacturers of dolomite limes, as well as the salt producers, as it would place a value on what is today for the latter a worthless product and a dead loss.

The Glass Industry.—The glass trade has been shown to be a heavy consumer of lime. The fact that ground lime proved to be so marked a proportion of the production, and that for the bottle and window glass trade, ground limestone high in calcium was used, led us to inquire why ground dolomite limestone was not used in the flint and plate glass industries in preference to the product of the calcination of this same stone. The manufacturers of lime state that they have tried to introduce the ground dolomite and put in machinery for its production, but had to abandon the idea, because the glass manufacturers would not use the product. Such of this machinery as could not be used for making ground lime has gone to the scrap pile. Another lime manufacturer who is well known in the glass trade, said in substance as follows: "We think that flint glass producers prefer the ground lime for the following reasons: *First:* The flint and plate glass manufacturer has found that in the process of manufacture as carried out today, the substitution of the ground carbonates, as represented by ground dolomite, together with the usual impurities which are not volatile, at glass-producing temperatures, introduce more defects in the finished products than does the ground oxides. *Second:* When ground carbonates are substituted for the oxides, the color is slightly off, nor is the brilliancy of the glass so great. *Third:* The glass producer must invariably receive his lime by freight and he considers that it costs him just as much to drive off the volatile constituents of limestone as it costs the manufacturer of lime to do so, and that by buying lime he saves paying freight on those volatile constituents, and at the same time gets a better product. *Fourth:* The use of ground limestone requires that larger glass pots should be used. These are very expensive. They are needed on account of the bubbling or foaming of the viscous, half-fused mixture which is formed at the time the carbonates are being broken up, and the volatile gases are coming off."

The reason why it seems impossible, or at least unprofitable, for the flint and plate glass manufacturer to use the raw carbonate, while the window and bottle glass maker uses it with perfect satisfaction, lies in the fact that the latter use large tank furnaces. In these, the surface of the glass is traversed by the flames and combustion gases, so that fresh batches of the charge are exposed to a fierce heat, and often to reducing influences, as they lie in a thin layer on the surface of the fluid glass. Thus, combination is carried on continuously, a little at a time, under very high temperatures, and under conditions favorable to the dissociation of the carbonate of calcium, sulphate of sodium and other glass making fluxes which do not decompose well in the milder action of an inclosed glass pot.

Further, the tank furnace is a long affair, fed with raw material at one end, and the finished and perfectly limpid glass is withdrawn at the other. The glass must travel slowly, hour by hour from one end to the other, and perhaps this time may even stretch out over several days before the glass finally leaves the tank. During this time, all minerals which would not easily be dissolved in a short melting period, gradually succumb in the long one, or are held back by skimmers, dipping rings, etc., so that they cannot be withdrawn in the good glass, until finally they are dissolved and disappear. This slow deliberate fusion, at high temperatures, and with direct contact with flames thus accomplishes satisfactorily, so far as perfect decomposition and solution is concerned, what cannot be at all well done in a closed or even an open-top pot, in a melting period of a few hours and at lower temperatures.

Insecticides.—Hydrated lime is also a large constituent in many preparations for the extermination of insects.

Slag Cement.—This product is manufactured in considerable quantities in Ohio. For this purpose, limes very low in magnesia are demanded.

Magnesia Covering Fireproofing.—For this purpose hydrated limes are much used as cementing and bonding material, which is a non-conductor of heat of the highest class

Steel and Tin Plate Mills.—These industries use some lime in connection with the pickling vats, for the neutralization of acids used in cleaning, polishing and burnishing the product. Either type of lime will accomplish the purpose.

Stone Sawing.—Lime is used in small quantity in the stone, marble and granite saw mills for the prevention of rust stains due to the abrasion of the steel saw blades. Either type of lime answers this purpose.

Fertilizer Manufacture.—These manufacturers use lime or tailings from the hydration plants or ground limestone for a twofold purpose. *First:* To neutralize acids used in converting insoluble phosphates into soluble ones. *Second:* To act as a filler, and later aid in liberating the nitrogen contained in some of the fertilizer constituents. Either type of lime is efficient.

Lime as a Carrier of Chemicals.—In the manufacture of acetic acid and bleaching powder lime is used as an absorbing or carrying agent. The active chemical agent is converted into a stable calcium salt, and in such form it can be readily, cheaply, and safely transported. When it is desired to liberate the acid material again, this salt is easy to decompose, setting free the active elements or compounds when wanted. High-calcium lime is usually demanded for this purpose.

Lime as a Purifying Agent.—In the treatment of water for boilers and sanitary purposes, considerable quantities of high-calcium lime are demanded. All elements or compounds other than calcium oxide are apparently inert, and definite quantities of this chemical agent must be added, so it is evident that the chemical composition should be known, and air slaked lime should be absent. Therefore, a hydrated high-calcium lime of known composition would be best.

Gas Purification.—In manufactured gas and in oil there are certain undesirable impurities which must be removed in order to destroy undesirable odors, etc. These undesirable compounds are mainly sulphurous in nature, and readily absorbable by lime or its products. Henry N. Clogg has proposed the use of hydrated lime for the purpose, and its value was fully shown by Winfor. Many other bodies have been used, but lime in the hydrated form seems to be the most desirable. It costs in England for purification of gas, from ten to twelve cents per ton of coal converted into gas. With some natural gases, it is necessary to remove sulphur compounds by passing it over lime.

Lime as a Disinfectant.—For ages lime has been used as a disinfectant and antiseptic, mainly in the form of quicklime, but there is no reason why hydrated lime which can be put up in convenient packages which will keep indefinitely, should not be just as efficacious. If so, it will supersede the use of quick ime for this purpose. Every grocer and dealer in general merchandise in the United States should have packages of hydrated lime on hand for sale for this purpose. Either type of lime is good.

By-Products of Coal Distillation.—When the products of the distillation of coal other than the illuminants are desired, lime is used as the caustic alkali. It liberates the ammonium, one of the desired products, which is given off as a gas and absorbed in water, forming the aqua ammonia of commerce. Either type of lime will answer.

Refractory Linings for Steel Furnaces.—For basic linings only dolomite limes are desirable. They are less affected by cooling and exposure to the atmosphere.

Soap.—Soap and glycerine manufacturers use considerable quantities of lime. The quantities required are so large that a few soap makers have their own lime plants. Slaked lime is used in the process of manufacture, to convert carbonate of soda and potash into the caustic hydroxide form. Practically all of the glycerine produced in the United States comes originally from garbage. Lime is a necessity in its production, as well as in the separation of the other products obtained from garbage.

Bone Ash.—In the manufacture of bone ash, acids are used to remove undesirable products. Lime is used for the removal of all excess acid used. The resultant product, a mixture of calcium chloride and calcium phosphate, is much used in fertilizer mixtures.

Tanning.—In this process, lime is used for two purposes. *First:* To soften, loosen, and even destroy the hair on the raw skins, in order to make it readily removable, as well as to put any adhering particles of fat and flesh in a condition for ready removal by scraping the hide. *Second:* The solvent action of the lime on the hide also produces an expansion of the pores, which is called "plumping" and renders the hide more capable of absorbing large amounts of oil and tallow, thereby taking on greater weight and solidity, which is the desideratum of all tanners. High-calcium limes are most desired for tanning operations.

Lime in the Textile Industries.—Lime has proven too drastic an agent for the purification process in both woolen and silk factories, but for the scouring of cotton it has been found to be excellent. For this latter purpose, the cotton is saturated with water and then boiled with a thin milk of lime. The insoluble soap formed with the fatty and resinous substances found in the raw cotton is removed with acids, preliminary to the bleaching process. A high-calcium lime is preferable.

Production of Ammonia and Potassium Bi-Chromate.—For the production of both of these chemicals, lime is used. The main source of the ammonia of commerce is ammonium sulphate, which when treated with lime in the form of either oxide or hydroxide yields the gaseous ammonia which is readily absorbable in water, making aqua ammonia. In the manufacture of bi-chromate of potash, it retards fusion and forms insoluble basic chromates. A very pure high-calcium lime is desirable for both purposes.

In Ceramic Mixtures.—The carbonates of calcium and magnesium are much used in both body and glaze mixtures, but there is no reason why the hydrates of the various limes should not replace the carbonates, making due allowances for the composition. It would be necessary to supply for this purpose hydrates of uniform composition. There is room and reason for the use of the hydrates of both types, each in its place, however.

The following table, prepared for 1902, is fairly representative of conditions during the last three years as well. The total annual lime production has been much the same with perhaps a gradual, but small, increase in the amount burned. The production in different sections has varied somewhat, and some new kilns have gone into operation. Delaware, Marion, and Clark counties will show increased production. Sandusky county, however, shows the most marked increase. In the spring of 1902, there were but a few kilns in operation at Gibsonburg and Woodville; now there are nineteen or twenty under constant fire and these points have two of the best equipped plants in the state, both turning the major portion of their output into hydrated lime.

Table XXIII—Approximate Production of Limestone by Counties. For the Year 1902.

County.	Number of men employed.	Building stone.		Crushed stone.		Lime burning.		Remarks.
		Geological Formation.	Perches.	Geological Formation.	Cubic yards.	Geological Formation.	Bushels, of 70 pounds.	
Allen	44			Lower Helderberg	38,000			
Butler	8	Hudson River	6,000					
Clinton	5	Clinton	1,200	Clinton	200	Upper Niagara	2,000	
		Lower Niagara	225					
Crawford	31	Corniferous	216	Corniferous	75,600			
Clark	182	Lower Niagara	24,579	Lower Niagara	71,461	Upper Niagara	560,000	Crushed stone about evenly divided.
				Upper Niagara				
Delaware	47	Corniferous	13,333			Corniferous	312,500	
Franklin	415			Corniferous	404,000			
Greene	85	Lower Niagara	6,500	Clinton	8,000	Upper Niagara	90,000	
						Lower Niagara	5,000	
Hamilton	5	Hudson River	5,000					
Hancock	61	Upper Niagara	4,000	Lower Helderberg	80,000			
Hardin	32	Lower Helderberg	95	Lower Helderberg	5,000			
				Upper Niagara	9,000	Upper Niagara	131,250	
Highland	102	Lower Helderberg	17,616	Lower Helderberg	49,340	Lower Helderberg	184,960	
		Clinton	206	Clinton	254			
Logan	60	Lower Helderberg	10,000	Lower Helderberg	50,000			
Lucas	45	Corniferous	8,750	Corniferous	55,800			
Marion	305	Corniferous	27,739	Corniferous	247,540	Corniferous	1,661,986	
Miami	115	Lower Niagara	35,100	Lower Niagara	16,800	Upper Niagara	60,000	
						Clinton	72,000	
Montgomery	35	Lower Niagara	8,000	Clinton	25,000			
Ottawa	485	Corniferous	1,085,652	Corniferous	506,640	Corniferous	2,270,000	12% burned at Sandusky.

Table XXIII.—Approximate Production of Limestone by Counties. For the Year 1902—Concluded.

County.	Number of men employed.	Building stone.		Crushed stone.		Lime burning.		Remarks.
		Geological Formation.	Perches.	Geological Formation.	Cubic yards.	Geological Formation.	Bushels, of 70 pounds.	
		....	......	Lower Helderberg.	56,000	Lower Helderberg.	200,000	
		....	......	....	......	Niagara	928,000	
Preble.........	77	Lower Niagara....	48,165	Lower Niagara....	5,834	Lower Niagara....	67,500	
Sandusky......	66	....	......	Lower Helderberg.	131,250	Upper Niagara....	189,462	
		....	......	Corniferous	222,000	....	......	
Seneca	120	Corniferous	10,700	Corniferous	168,000	....	......	
		Lower Helderberg.	3,500	Lower Helderberg.	62,100	Lower Helderberg.	78,750	
		Upper Niagara....	500	....	......	Upper Niagara....	653,214	
Van Wert......	150	....	......	Lower Helderberg.	275,000	....	......	
Wood	121	Corniferous	9,000	....	......	Upper Niagara....	450,000	
		Lower Helderberg.	1,034	Lower Helderberg.	2,500	Lower Helderberg.	570,375	
Wyandot	10	....	......	....	......	Upper Niagara....	60,000	
Total......	2,606		1,327,110		2,565,319		8,555,907	

CHAPTER VI.

TECHNOLOGY OF THE LIME INDUSTRY.

BY S. V. PEPPEL.

DEFINITION OF LIME.

The most important purpose to which limestone is applied is the manufacture of lime, which is the basis of the mortar used in masonry and brick construction, and of the plaster used in covering the interior and sometimes exterior walls of all kinds of houses. While in tonnage the quantity of limestone applied to this purpose is less than that used in other ways, its value, measured by the inconvenience of doing without it, is vastly greater. No other material now known and widely available could take its place as a substitute. Aside from its use in the building industry in mortar, plaster, stucco, etc., lime finds a very great use in various chemical industries, paper making, sugar refining, soda ash manufacture, fertilizer manufacture, sand-lime-brick manufacture, etc. It is the cheapest and most readily procurable of the strongly basic oxides, and is of the greatest use as an alkaline agent in manufacturing chemistry.

Lime, or quicklime, is the name applied to the common or commercial forms of the oxide of calcium. In the chemical sense, lime *is* calcium oxide, and if one were to buy lime from a chemist for use as a chemical reagent in a laboratory, he would obtain the oxide of calcium, chemically pure.

In the practical, every-day use of the term, however, lime and calcium of oxide are not synonymous, for it is not practical to furnish chemically pure calcium of oxide by the ton or carload, nor is chemical purity essential for ordinary manufacturing and construction work in which lime is used on an enormous scale.

From the ordinary commercial standpoint, lime may be defined as a material obtained by the calcination of a stone in which carbonate of calcium is the predominating ingredient. Thus it at once appears that the character of a commercial lime will depend on the limestone from which it was produced, as well as on the treatment it receives in burning and cooling, and that while the calcination of any limestone yields lime, there are very great differences in its character and purity. On account of these variations, the term lime has no fixed or settled meaning or standard of purity in the courts, or in practical and commercial work, and limes may be found on the market varying in all degrees from approximate chemical purity down to materials in which the calcium oxide is less than fifty per cent. of the whole.

While the oxide of calcium is the chief or preponderant active substance in all lime, it is almost always accompanied by the oxide of magnesium, a closely related substance, also basic and alkaline in chemical nature, and capable of acting in many respects like lime, as a mortar material, flux, etc. Because of this similarity in general nature, the oxide of magnesium is not considered as an impurity in limes for ordinary purposes, like mortar making. For strictly chemical uses, like cement making, sand-brick, soda-ash manufacture or sugar-refining, the magnesia does not act the same as lime, and cannot be substituted for it, and hence for these purposes it is called an impurity. In the manufacture of flint and plate glass, the magnesia is considered a highly desirable constituent.

The impurities of commercial lime, which are popularly recognized as such, are clay, sand, oxide of iron, and other materials of this sort. These substances affect the value of the lime in two ways. *First:* By dilution. They have no chemical activity similar to lime, as magnesia has, and hence weaken its action in proportion to their amount. *Second:* They rapidly deteriorate the color of the lime, making it gray, or yellow and unsightly. *Third:* They interfere with the calcination process, by causing the lime to flux and melt, or by hindering the rate of the expulsion of the carbonic acid, so that the product is lumpy and irregular. *Fourth:* The undesirable impurities, if present to the extent of five per cent., or in excess of that, are very likely to make the lime work poorly under the trowel. *Fifth:* If these impurities are of a certain kind and fuse to certain undesirable or unstable combinations, as is frequently the case in burning, they are very likely to cause pitting on the wall in plaster work. For the setting of brick and masonry work, this latter fault as well as that due to coloring matter is an unusual one.

The elements or compounds which are considered impurities in white lime, using this term in its commercial sense—i. e., lime containing less than five per cent. of clayey or sandy matter—are not so considered when speaking of the gray or hydraulic limes. These same elements are essential in their make-up, and it is through their action that the distinctive properties of hydraulic limes are developed.

The term lime therefore has no exact meaning. It means calcined limestone, but unless the proportion of the various ingredients are specified in advance, and agreed upon by both parties in a transaction, one would not be able to hold the other to any particular kind of lime or grade of purity. It might be very highly magnesian, or pure dolomite lime, or it might be practically pure calcite lime, or it might be any mixture between these two extremes, and yet be considered good lime in each case. It would not be considered a good white lime if it were decidedly gray, or silicious, or lumpy, and did not slake freely with water. Hydraulic limes, however, are expected to be gray, more or less silicious and as a rule to slake rather slowly.

CLASSIFICATION.

For convenience, it is necessary to classify limes according to their physical and chemical properties.

Dr. Edward Orton, writing in 1887,* classified limes as follows:

"1. Limes derived from stone containing eighty-five to ninety-five per cent. carbonate of lime.

"2. Limes derived from stone containing seventy-five or eighty-five per cent. of carbonate of lime and about twenty per cent. of carbonate of magnesia.

"3. Limes derived from stone containing sixty-five to seventy-five per cent. of carbonate of lime and twenty-five to thirty per cent. of carbonate of magnesia.

"4. Limes derived from stone containing approximately fifty-five per cent. of carbonate of lime and forty-four per cent. of carbonate of magnesia (dolomites)."

These divisions have not been widely accepted. The popular classification recognizes but two kinds of lime, which they call gray or hot lime, and white or cool lime.

These terms are not sharply defined, nor do they separate limes along easily distinguishable characteristics, for all gray lime is not hot, nor is all white lime cool. The basis of classification into hot or cool lime is the fact that calcium oxide combines with water to form calcium hydroxide (slaked lime) with very great energy, and the evolution of much heat, while magnesium oxide combines with water with much less energy and much less heat, if it slakes at all, in the short period of time usually taken for the slaking of lime. Magnesium oxide prepared at low temperatures does slake or take on water of hydration, slowly, with the evolution of heat. There are those who believe that the magnesium oxide contained in lime takes on practically no water of hydration at ordinary temperatures. There is good ground for this belief. *First:* The magnesium oxide contained in any lime must necessarily be badly overburned before the calcium oxide is produced. *Second:* The heat of hydration of a dolomite lime is practically all accounted for by that which the calcium oxide present would develop on slaking. *Third:* The amount of water taken up by dolomites when slaked by most mechanical slakers is essentially all accounted for by the hydration of the calcium oxide present. The slower rate of slaking for limes containing magnesium oxide is no doubt due to the dilution of the calcium

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oxide with an essentially inert material which hinders in bringing the water in close contact with each particle of calcium oxide and at the same time absorbs the heat generated by the slaking, and thus cools and retards the chemical action. Other things being equal, the more magnesium oxide present, the slower and cooler the slaking process. The same proportion of very finely ground sand mixed as intimately with the calcium oxide as is the magnesium oxide would have the same effect. This trait of the slow slaking of limes containing magnesium oxide is not necessarily a detriment, but in many markets is considered very desirable. If, therefore, a commercial lime has been burned from a limestone consisting chiefly of calcite, it will produce a "hot" lime or a "quick" lime, but if the limestone was strongly magnesian or consisted of the mineral dolomite (a double carbonate of calcium and magnesium containing fifty-six per cent. of carbonate of calcium and forty-four per cent. of carbonate of magnesuim), the lime would be called "cool" or "mild" or "slow."

The basis of the classification by color into gray and white limes is that the dolomite burned in Ohio is comparatively free from clayey, silicious and ferrugineous coloring matter, yielding a very white lime, and that the high-calcium limestone burned nearly always carried sufficient coloring matter to give it a mild gray color. The terms white and gray as applied to limes should be abandoned in their present accepted meaning, since some of the high-calcium lime burned is nearer white than some calcined dolomite. It is only in rare instances that this would be the case in Ohio, but there are sections where the terms gray and white have exactly the opposite meaning to that accepted by Ohio producers and users. In some markets it is customary to further qualify the terms white or gray by adding to it the section of the country from which it comes in order that the customer may know what type of lime he is getting.

The terms in use in Ohio, and the United States generally, ought to conform to the general usage elsewhere, and we ought to accept the same limes by the same names as are known in other countries. White lime should include all limes with less than three per cent. of total impurity. These, as a rule, will be very nearly white. Gray lime should cover all that carry more than five per cent. impurity. Gray lime and hydraulic lime should be synonymous terms.

The classification proposed by Dr. Orton seems too complicated; i. e., it makes too many divisions of white lime for practical needs, and also fails to consider the gray or hydraulic limes. The system or usage of the public is perpetuating a misleading or erroneous classification. It seems proper, therefore, to propose the following classification which is in harmony with that used abroad, and in accord with our commercial and technical needs as well:

TABLE XXIV—CLASSIFICATION OF LIMES.

White limes Containing usually less than three and never more than five per cent. of sandy and clayey matter.	1. High-calcium, or "hot," or "quick" limes. Made from limestones containing not less than 85 per cent. of carbonate of calcium.
	2. Magnesian limes. Made from limestones containing between sixty-five and eighty-five per cent. carbonate of calcium and between ten and thirty per cent. of carbonate of magnesium.
	3. Dolomitic, or "cool," or "slow" limes. Made from limestones containing more than 30 per cent. of carbonate of magnesium.
Gray Limes. Containing from five to thirty per cent of sand and clayey matter.	4. Hydraulic lime. Made from limestones, either high-calcium or dolomitic, which contain from five to ten per cent. of sandy and clayey matter and which will slake by themselves when placed in water. They gradually harden under water.
	5. Natural cement or roman cement. Made from limestones, either high-calcium or dolomitic, which contain from ten to thirty per cent. of sandy and clayey matter; and which will not slake, without first being finely ground. They harden under water much more rapidly, and to a harder final product, than hydraulic lime.

The gray, or hydraulic limes are not produced at all intentionally, or as an article of commerce, in Ohio. There are a few localities where a lime of decided grayish color is produced on a small scale for local use or for agricultural purposes, and does not enter into competition with the white lime of commerce. But the total amount of such product is small and is confined to out-of-the-way places. The roman cement industry has been considered at length in Bulletin 3, of this series, and will not be taken up here further than to state that there are a few decadent industries of this sort in Ohio. They are gradually dying out, as there are several less now than ten years ago, and no new ones have been established. Nevertheless it is by no means assured that there is not a legitimate field for roman cement manufacture in Ohio, if the industry is put on its feet and given high grade technical supervision, and the best modern methods of production. The materials for the industry are here in profusion, in many parts of the state.

In the balance of this chapter, only the white lime division will be considered, as this is really the only lime of commerce, so far as Ohio is concerned. In fact, the great majority of Ohio limes as manufactured today fall within classes two and three. The product of only a very few plants will fall in class 1. Most of the plants in class 2 have quarries that produce stone that could make lime belonging in class 1, but this stone is used for other purposes and that with a little more magnesium carbonate given preference for lime burning. It keeps better, and is not so violent in slaking as the other would be. It is probably a trifle whiter also. All the limes of class 2 burned in the state have a grayish or a skim coat for use as it is, or in condition to appear well with kalsomines or paints. If the wall is white and smooth, his employer is satisfied.

While the dolomite limes require more time in the putty form to completely slake and ripen, they are less susceptible to taking on a lumpy condition due to local "burning" in slaking, and since they contain some very fine material apparently inert, and will not carry so much sand, there is nearly always served to the workman a richer mortar which works more smoothly than a highly-sanded mixture. This is probably the fundamental principle which causes the conditions to obtain on which this preference is based.

Some adverse criticism of high-calcium limes would be removed, if in practice it were used in all mortar mixtures pound for pound with the amount of dolomite lime required for a mortar of satisfactory working qualities.

Both types of lime suffer in the estimation of the workman, the contractor, and the customer, on account of a lack of knowledge how to properly slake each, in order to get the best results possible in each case. The man who has thoroughly learned how to handle one lime, and get the best results, will invariably get poor results with any other. One solution of this problem will be the extensive use of hydrated limes of both types, which have been prepared under the most advantageous circumstances, and under the direction of those who understand fully how to handle the lime in order to get the best possible results from it.

Infuence of Machine Mixing.—Another solution to the problem will be the more extensive use of machine-made or wet mortars. This is only feasible for the larger towns and the cities. There are many reasons why a properly prepared machine-made or wet mortar should be better, and consequently preferable, to hand-made mortars mixed on the job. *First:* The limes are slaked by the aid of mechanical mixers, and by men who have studied just how to handle the particular brand of limes used. The operator knows just how stiff his putty should be, and just how long it needs to stand for proper ripening before use. *Second:* He uses almost invariably mixtures of the two types of lime, varying the proportions of hot lime and cool lime to suit the requirements for a good mortar for each purpose used. For instance, for finish or white coat, practically all dolomite lime is used. For laying front brick only a small amount of hot lime is added, while for common brick and back walls more is introduced. For first coat work, which is very rich in lime, some hot lime goes in, while for the setting of masonry and all rough work needing a large amount of quick-setting mortar, the high-calcium lime is the main constituent.

These mixtures of limes are not made in order to cheapen the product, but to improve the qualities of the mortar, especially the working qualities of it, each for its specific purpose. The dolomite or highly magnesian limes are added to the hot or high-calcium limes for two reasons. *First:* Mortars made from the very hot limes alone are too washy and sloppy to handle easily, before the setting up reaction begins, and after this starts it is so rapid as to get hard too soon for convenience. The addition of the dolomite lime gives it better body and retards the setting up. The introduction of any inert substance, either amorphous or in the finely divided state, such as a very fine sand carrying a little loam or fine limestone dust or fine marl, would no doubt aid in eliminating the first undesirable quality of the high-calcium lime mortar, but would probably have but little influence on the retardation of the setting up. In fact, it is probable that the presence of small quantities of very fine quartz or sand and clay would tend to accelerate it. The dolomite lime is said to add toughness to the mortar.

Second: On the other hand, dolomite limes used alone are for most purposes considered as working too heavy, too tough, and too difficult to distribute rapidly over large surfaces. The addition of hot limes materially improves the spreading or working quality of such mortars. From the above statements, it is evident that for most purposes mixtures of the two limes will be found desirable. This, however, would impose a hardship, or at least be inconvenient, for the man preparing small amounts of mortar by hand, but is be entirely feasible, and is commonly done by the machine mortar manufacturer.

The large mortar manufacturer frequently finds it advantageous to use mixtures of two or more sands for the best results. To do this would also be troublesome to the contractor using only small quantities each day.

One manufacturer gives the following reasons why machine-made wet mortar should be used in preference to that prepared by hand-mixing:

> "First: Superior quality. Second: Made on scientific principles. Third: Uniformity. Fourth: Thoroughly mixed, blended and ripened. Fifth: Cheapness. Sixth: Delivered as required. Seventh: The absence from building fronts of piles of sand, mixing rings, slaking boxes, barrels of lime, all impedimenta, etc., used to make mortar by the hand method in vogue.
>
> "By the use of machinery a cheaper and more thoroughly mixed mortar is produced than is possible by hand, and one that will work easier and smoother under the trowel."

The use of mechanically prepared wet mortar has shown a steady increase for a number of years and will probably continue to do this for some time to come. The reports of the future will show the mortar factories as among the larger consumers of lump lime. Today they are considered an important factor in the lime trade, as it is shown by the statement of Mr. F. C. Ferris, of Columbus. It takes about two hundred and fifty car loads of lime per year to supply his factory. He is a prominent mortar manufacturer, and very kindly furnished every facility for studying conditions in his factory, as well as in the observation of structures for which he had furnished the mortar many years ago.

There are several properties of the two lime putties as prepared commercially which were brought to attention very forcibly by observations in the Ferris factory. They are well known to everyone handling large quantities of lime putties of different kinds, but they are not generally known elsewhere, and hence are mentioned here.

First: The volume of putty produced per pound of lime in the oxide form is not materially different for the two types. If there is any difference, it is in favor of the hot lime for the larger amount.

Second: The two putties leave the slaking machine at about the same degree of viscosity. If there is any difference, the dolomite lime putty flows the more freely of the two. In a very short time, however, the dolomite lime putty is much the firmer of the two.

Third: On standing in the vats to ripen, the high-calcium or hot lime putty shows a much more marked shrinkage than does the other. In spite of this shrinkage of the hot lime putty, when equal volumes of putty of each variety are taken, and sand is incorporated, it will require a considerable excess of sand with the hot-lime putty mixture, or an addition of much more water to the dolomite lime putty to bring the two mortars to the same consistency. This putty shrinkage of course is a measure of the mortar shrinkage, and means that if two mortars are made up using the same amount of sand in each, and the same weight of lime of each type, properly slaked in each case, the mortar made from the hot lime will have a greater shrinkage factor and be more apt to crack on drying out and hardening. The larger use of sand in the hot lime mortars reduces this shrinkage factor, so that in the mortars as usually applied there is not such marked evidence of this difference in the behavior of the two mortars.

For many years to come, there will undoubtedly be much lump lime of both types slaked in comparatively small batches, and usually by unskilled labor. The following explicit directions for the slaking of each type of lime have been prepared, using as a basis the best practice by those working constantly on each type of lime. It is a simple operation to the initiated, but it is difficult to describe it in such a manner that one who has never seen lime handled, could make an absolute success of his first attempt at slaking. Each lime slaker seems to have his own method of realizing the critical points in this operation. These critical points do not appear important to the beginner, but they are often the cause of a poor mortar being made.

Slaking of Dolomite Lime.—Put into the slaking box enough water to slake the desired amount of lime before the lime is put in. The proper amount of water for a good putty will be about one pound for each pound of lime—that is, twenty to twenty-five gallons for each barrel of lime slaked. The amount needed will vary with weather conditions, taking a little more in summer and less in winter to accomplish the same results.

Dump the lime in and quickly spread it in an even layer and of such a thickness that it shall practically all be covered with the water. Now leave it undisturbed until slaking is practically completed. Mix just sufficiently to equalize the density of the mass. If only a small quantity is slaked in a small vessel, probably no stirring will be necessary. If during slaking small puffs of dry steam, or smoke as it is sometimes called, appears, the mass should be stirred at that point, to let the water into the lump or lumps, since this dry steam is due to a local overheating and an absence of water to absorb and relieve that heat. Cold water should not be allowed to run into the box from a hose during slaking, since it will chill the lime locally, and stop the slaking process at that point. The lime should not be disturbed during slaking, except such movement as is necessary to prevent the local burning as mentioned above.

Slaking of Hot Limes.—The same general directions as given for dolomite limes will hold here also. Put the water into the box before putting in lime, and stir only to prevent burning. To accomplish this will require close watching, and at critical moments vigorous work may be needed to get the water into contact with all parts of the lumps which need breaking up. A coat of hydrate forms on the outside of these lumps, which acts as a waterproof envelope, and permits only small amounts of water to penetrate to the main portion of the lump. If such lumps are not broken up, the lime will be bad in spots, both from burning in some parts and imperfect slaking with too small a quantity of water in other portions. For the hot limes, considerably more water is needed on account of the greater heat developed, which causes a larger amount to go off as steam during the slaking process. Where lime is slaked in large quantities, especially in the winter time, many contractors prefer to use warm or tepid water. The wet-mortar works as a rule use tepid water the year round for both types of lime. They run water into their slaker and dump lime in at the same time, until they have gotten a proper proportion of each, then let it stand till well heated up, when the stirring device breaks up the lumps and produces a homogeneous mass. This is then run over the screen for the removal of core, etc., and then goes on to the storage vats. Some of the manufacturers of dry hydrated lime either use warm water or introduce a little steam at the beginning of the slaking process.

PROCESSES OF MANUFACTURE.

The processes of manufacture of lime are simple. The mere heating of a piece of limestone for a few hours to a bright red heat is sufficient to disengage its carbonic acid and bring it into the caustic or "quicklime" condition. This has been done from time immemorial in the crudest of ways, by the most ignorant and inexperienced of people, and the idea thus gained ground that there was room for no better methods or the use of more intelligence and training. Lime burners, like common brick makers, have been looked upon as representatives of a low-grade occupation.

The real fact is, however, that both industries are founded upon chemical processes or reactions, and that while a partial success can be gotten in these processes with very little knowledge or experience, the attainment of good economy or high-grade efficiency in either demands skill and intelligence of a high order, which cannot be reached without the use of technical methods, and scientific training. The manufacture of quicklime is now undergoing a rapid transformation from the old, crude, pot-kiln industry, in which the burner sold the product of his own kiln, into a large, finely equipped business in which every detail is adjusted to minimum waste and maximum output. Within the last few years there has been a very decided awakening and the larger and better lime manufacturer no longer thinks that he knows everything worth knowing about the production of lime. He is in search of all reliable information today and ready to make improvements wherever there is a reasonable chance of such changes producing greater economy. He is now beginning to feel that the use of technical methods and scientific training can probably do as much in the advancement of the lime industry as they have for most of our large industries. Until quite recently, the scientist, the chemist, and the technologist have received but little consideration from the lime manufacturer, who has been the greater loser of the two on this account. A properly prepared technologist can be of great service to the lime manufacturers of the United States. The manufacture of quicklime may be considered under the following steps or stages: *First:* Quarrying the raw material. *Second:* Burning. *Third:* Cooling. *Fourth:* Preparation for market. *Fifth:* Hydration.

QUARRYING LIMESTONE FOR LIME-BURNING.

The winning of limestone always involves quarrying, as no form of carbonate of calcium which has the requisite hardness to stand up in the kiln and in transportation is soft enough to be dug by hand or by steam shovel. The marl beds supply carbonate of calcium of great purity, but it is ruled out from lime burning on account of its fine sandy texture, which would choke a vertical or shaft kiln at once. Travertine, or recently deposited calcareous tufa, from springs, etc., is sometimes soft enough to dig and hard enough to stand handling and burning, but the quantity available is commercially insignificant.

Quarrying is the standard method of winning stones of all descriptions. It is an industry by itself, with a great variety of methods of working adapted to rocks of different hardness and texture and cleavage. The quarrying of granite, marble, slate, sandstone, limestone, etc. for building purposes is different in each case, but in all the object is the same; i. e., to get the material out in blocks of definite shape and size. To this end expensive machinery is employed to cut around the blocks, to put in holes in great numbers for wedges, and in every way reduce the shock or jar by which the final separation of a mass of stone from the quarry bed is brought about. This kind of quarrying is very slow and costly. A short discussion of the methods and tools used in quarrying limestone as a building material is given in the preceding chapter.

In lime burning the purpose of quarrying is merely to break the rock from its matrix in fragments of suitable size, and with no restrictions as to shape. This process is a simple one, dealing with but few methods and utilizing, for the most part, low grades of labor, and very little machinery.

It is not the intent to go into a general discussion of the art of quarrying stone at this place. Suffice it to say that, in general, limestone must be loosened and broken out by blasting. Hand-power tools, bars, levers, drills, wedges, etc., are too slow and costly. The universal method of loosening is to drill a hole into the rock to a sufficient depth for the particular place and purpose, load it with black powder or dynamite, tamp the charge in with earth or stone chips, and explode it. The quantity of rock disengaged varies from a few hundred pounds to thousands of tons, according to the size, depth, and location of the hole; the quantity and kind of explosive; the hardness, tightness, and mineral structure of the rock, and the position of the hole with relation to the free or disengaged faces of the quarry. "Pop-shots," composed of an inch of a stick of dynamite, placed in a hole three or four inches deep, or even on the surface of a loose rock, suffice to break up and loosen a few hundred pounds. Ordinary working shots, composed of five or six sticks of dynamite, or one keg of black powder, placed in a drill hole two inches in diameter and eight or ten feet deep may loosen from ten to one hundred tons, according to location and nature of rock. Large or important shots may use large quantities of explosives, cost hundreds of dollars to prepare, and may make loose material for weeks of steady work in removal.

The requirements in quarrying limestone for lime-burning are different than when operating for any other purpose. The intent is to produce the greatest amount of stone of the largest dimension which will burn in a reasonable length of time with a minimum amount of care,

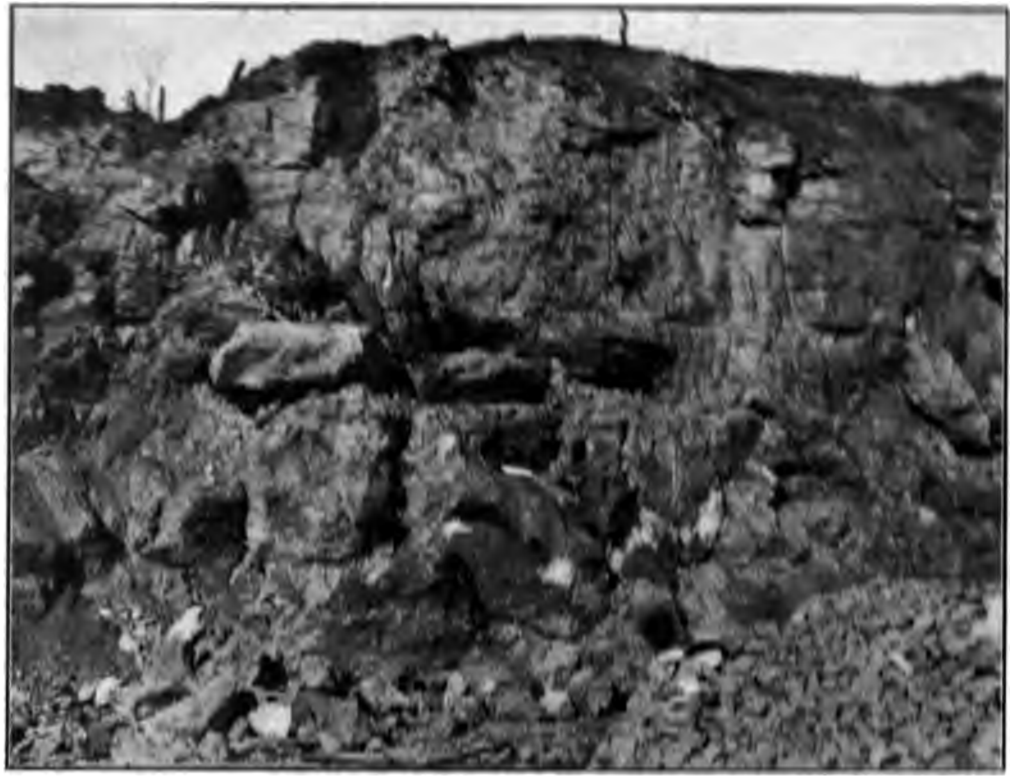

Figure 16.—View of the working face of a typical lime-quarry. The coarse material at the foot of the cliff has been dislodged by a blast and is now ready to be sledged down to size for burning.

and at the same time leave the smallest amount of material too fine for burning into lime, on account of the fact that small stone fill the interstitial spaces in the kiln and choke the draft. The stone may be of any size or shape for two of its dimensions, but must not exceed about five inches in thickness. With stone having a greater thickness than five inches, it is very difficult to get complete burning to extend to the center of the stone, without seriously overburning the exterior. On the other hand, only a small amount of stone such as would pass a 4-inch ring and be retained by a 2-inch ring can be used on account of its influence on the kiln draft, especially when dependent upon natural draft, as most limekilns are. The use of forced or induced draft, however, permits the use of a larger percentage of small stone. For many lime manufacturers, the fine stone is not only a dead loss; it is source of expense to move it and an annoyance to find a place to put it, where it will not interfere with the future working of the plant. For this reason, the quarry operation is planned to produce as little of the small stone as possible, even though it costs more per ton to get the rock out. On this account the quarryman places his shots, and uses his explosives, with a view to breaking the stone out with as little shattering as is feasible, producing large masses that can be readily reduced by pop shots or sledging. The cost of sledging or breaking these masses in a lime quarry usually exceeds the total of all the other quarry costs, where rock is taken out for lime burning only. This cost can be much reduced by using heavier charges in the shots in quarries where crushed stone is sold in connection with lime. The crusher uses all the stone too small for the limekiln. Some lime manufacturers are running crushers, not as a direct means of profit but as a means of saving a part of the quarry cost of the lime production.

Limestone is among the easy rocks to quarry. The hardness of calcite is only 3 and steel is 6.75 to 7, so that drills cut it readily. The presence of flint nodules or seams makes the stone much harder to work. Sandstone, though composed of individual grains of a hardness of 7, is not usually dense or solid in its rock structure and under blows the grains loosen from each other readily. Shale cut very easily also, so that locally in Ohio, limestone is the hardest rock quarried. But compared to granite, or any other igneous rock, it makes easy working.

The older quarries operated on a small scale generally still use hand drills, with or without sledges, for putting in the holes for blasting. In all the larger modern quarries, present practice is to use compressed air drills; the smaller up-to-date ones use steam drills, having portable boilers for steam supply, on account of the loss from condensation by long-distance piping of steam. It would probably be economy to put in air compressors at many of the quarries now using steam drills. After the first cost, the expense of operating by compressed air is very light, as compared with the cost when operating by steam or hand power.

Quarry Costs.—Almost every degree of efficiency is represented in Ohio quarry operations, from the poorest management to the most economical. At a few points limestone is being delivered to the crusher at a cost of about twenty cents per ton. This would mean about forty cents per ton of lime produced, if similar stone could be used for lime, but we have already pointed out that the requirements were different and that for lime burning the quarry cost must exceed this. The following actual costs taken from the books of three Ohio firms who represent about average conditions show the total quarry cost from its location in the rock bed until it is in the kiln, on the basis of cost per ton of lime produced:

One manufacturer gave as his average total quarry cost for one year per ton of lime made as sixty-seven cents. It cannot be stated, however, whether fuel was included; if not, there would be an addition of ten to twelve cents to this cost. No crusher was in operation in connection with this plant.

Another manufacturer gave as the average for 1905:

Total labor, explosives, etc., per ton of lime produced	66.6 cents
One-fifth of his total fuel cost	14.9 cents
Total	81.5 cents

Another manufacturer, who has a crusher to take care of the fine rock, gave the following as representing the costs for one month of 1905; all figures based on a ton of lime produced:

Quarry foreman	4.35 cents
Drilling and shooting	4.00 cents
Breaking, sledging, etc	30.80 cents
Driving and loading cars	5.76 cents
One-half engineer, fireman, and extra labor about plant and quarry	8.00 cents
One-fifth total fuel cost	12.91 cents
Stripping	.12 cents
Total	65.94 cents

The total cost of getting the limestone into the limekilns of the state ranges from sixty cents to eighty-five cents per ton of lime manufactured, at the various plants. With the majority this cost exceeds seventy cents rather than falls below that figure. From observations elsewhere it is safe to say that the average Ohio operator is doing this work as cheaply as it can be done in other states, and it is probable that in some of Ohio's best plants this cost would be very close to that representing the minimum for the United States.

Transportation to the Kiln.—There are still a few small old-time plants where the stone is hauled from the quarry in carts, dumped on the ground and then elevated to the top of the kiln by a hand-power hoist, using a big sheet-iron basket to hold the stone. There are also a few where the limestone is carted up a steep incline to the top of low kilns, where it is either dumped into the kiln, or on a platform, and shoveled in later. These methods are both very crude and should be abandoned. At a few points where the kilns are located on lower ground than the quarry, the stone is run out by gravity on trestles to the tops of the kilns. The great majority of the manufacturers today use an inclined tramway and cars operated by a drum and cable for elevating the stone direct from the quarry to the kiln. Some haul the stone to the base of the incline in carts and dump into the cars. Others have more cars and a complete track system in their quarries and load direct to the cars that go up to the kiln. The cars are run to the base of the incline usually by gravity and then hooked onto the cable. This is the most economical way of handling the stone. Very little has been done so far in the way of using automatic dumping. This should be looked into, since practically all the kilns have storage hoppers for holding enough stone for at least one day's supply. Since conveyors, which have been tried in other states, have thus far proven unsatisfactory, we must conclude that the inclined tram, with automatic arrangements for dumping, would represent the best practice for this purpose. It is not so expensive to install as would be the automatic dumping skip as used at blast furnaces. The latter, however, when once installed would give but little trouble in operation. There might be some difficulty in adjusting the automatic-dumping tram system to accurate enough operation to meet the requirements of those using induced draft and closed-top kilns. Sugar refiners' limekilns usually have a vertical lift and dump into a movable bell, operating just as old blast furnaces formerly did.

BURNING.

The burning or calcination of lime is a chemical process, which may be brought to a moderate degree of success with the use of little skill and no chemical knowledge. It suffices to merely place the limestone in a common stove or bonfire or in any kind of furnace where it will become red hot. The decomposition of the carbonate takes place at a red heat, more or less completely according to the other conditions, but still yielding lime, whether economically or wastefully, if the red heat is attained and maintained a few hours.

Consequently, our pioneers made their lime by burning the stone in heaps, on the ground, using logs to surround and cover the limestone, and keeping up the firing until the whole center of the fire had been visibly red hot for hours. The lime obtained from such a pit would be very imperfect—there would be hard lumps or cores of undecomposed stone in the center of the larger pieces and the small pieces even might be insufficiently burnt around the edges of the pit or in the center.

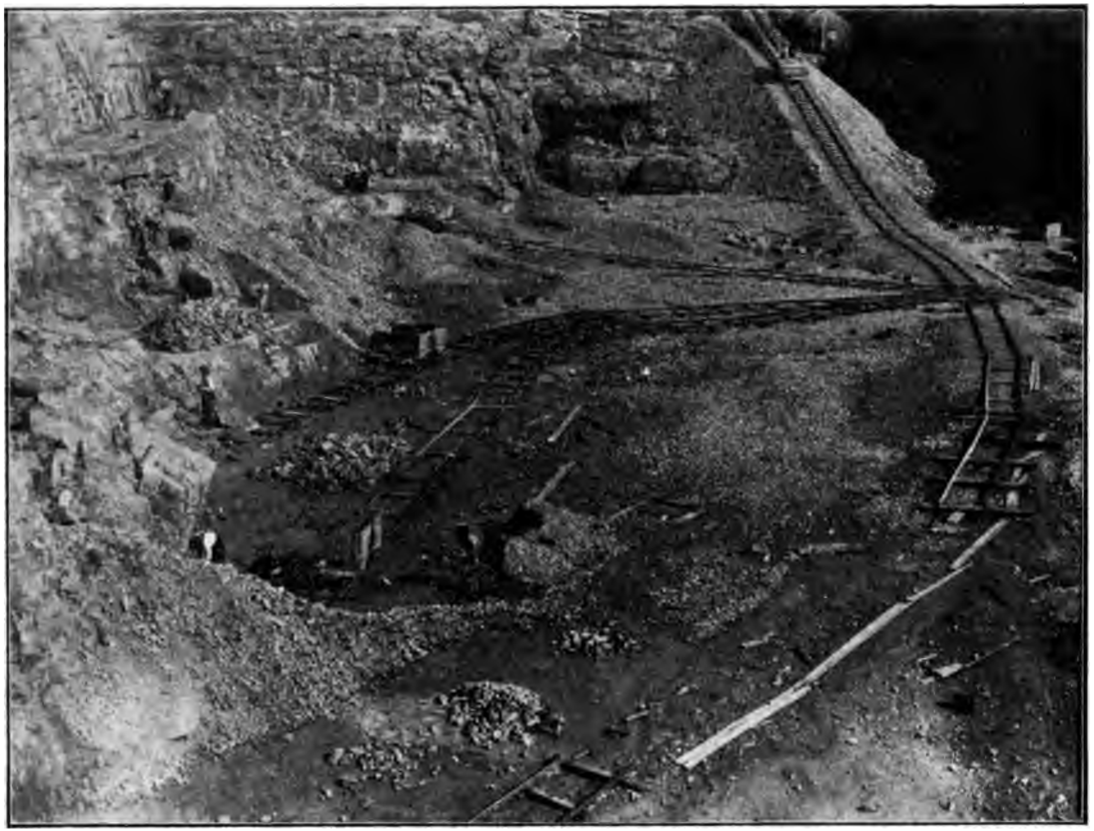

Figure 17.—Showing the lime-quarry of the Seneca White Lime Company, and system of moving the limestone from the quarry to the kilns, by tram cars, portable tracks, and incline hoist.

But the good was readily separated from the bad by slaking. The lumps which would not slake were removed from the box and that which did slake made a very good mortar, entirely sufficient for the needs of the time. Lime pits of this sort may still be found in backwoods communities. This primitive method is exceedingly wasteful of fuel, and produces but a small yield of good lime. It is mentioned merely to show how simple the process of manufacture may be if once the economy of the process is allowed to drop out of consideration.

On the other hand, every step and every factor in the operation of lime burning has a definite significance, and the production of a high-grade lime with high-grade economy is as truly a technical process, demanding skill and knowledge, as any other chemical manufacture. There is need of trained chemists in this industry to put it upon a distinctly scientific plane.

The Kiln.—Lime is burned in vertical shaft furnaces or kilns, usually of very simple construction. There is much variation in the diameter, cross-section, height, material of lining, fireplaces or method of using the fuel, length of cooling chamber, etc. The first form of kiln to supplant the open heap or "pit" is the so-called "pot" kiln, in which the fuel and stone are fed in at the top together. This is a cylindrical shaft or inverted truncated cone from eight to fifteen feet high and four to eight or ten feet in diameter. It is usually built of limestone or stone masonry of some sort, and crudely braced with iron tie rods. In some instances, it is built in a shaft excavated from the solid rock and close to the edge or face of a quarry, so that the stone is dumped in at the ground or surface level of the top of the bank and removed at the ground or surface level of the bottom of the pit or quarry. In this case, no bracing is required, but the cavity of the shaft must be kept from extending by lining it with firebrick or sandstone.

The pot kiln is still in use in Ohio at some few locations. Its day is on the wane, however. While at first sight there is not much change in limekiln construction in the last fifteen years, since most of the old kilns are still standing and many are operating, the fact is that changes are in progress all the time and all pointing to a much higher grade of technical results in the lime industry.

The use of coal as a fuel is almost universal now in the larger plants, and with it kiln construction tends to slightly narrower and higher kilns. The use of coal has also led to the use of forced or induced draft by steam or fans, or by some patented system whereby the hot gases from the kiln after partial cooling in the stack are drawn out and forced through the kiln furnace again. Aside from this, the tendency is to reduce hand labor as much as possible by the use of conveyors and horse carts instead of wheelbarrows. The tendency is to have better housed

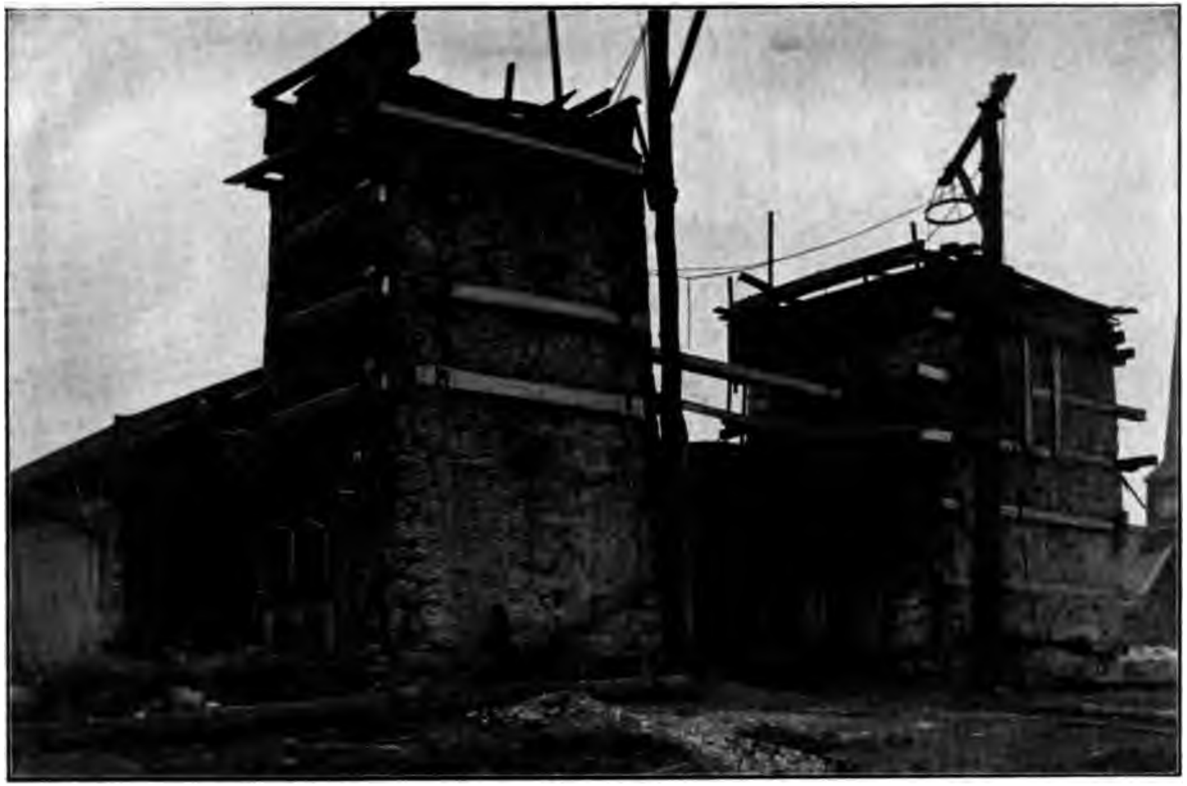

Figure 18.—Old type of draw-kiln at Gibsonberg, Ohio. The crane for charging the lime is an interesting relic of the old method of operating.

plants and to centralize production. Instead of eight or ten different plants operating one or two kilns each, the tendency is to get all these kilns together on one location and operate them as a unit.

The kilns constructed in recent years differ from the old pot kiln. *First:* The fuel is burned in furnaces and not mixed with the stone as was the case with the former. *Second:* The kilns are arranged so that the operation is continuous, the kiln is never emptied and cooled except for repairs. *Third:* The kilns are of greater height. *Fourth:* They have a less diameter also. *Fifth:* Coal is almost universally the fuel used. *Sixth.* The introduction of systems for preheating the air supply has begun. *Seventh:* The use of a jet of steam for forcing the draft is common. *Eighth:* The use of draft forced or induced by mechanical agents is now common. *Ninth:* Natural gas is used as a fuel in some places. *Tenth:* The installation of gas producers and the use of artificial gas has been tried successfully. *Eleventh:* The use of systems of semi-gas producer firing has also been tried. From the above statements, we see that there have been made many changes in methods of lime burning and many innovations introduced since the time of the old pot kiln. With all these improvements, which have increased the capacity, reduced labor, and improved the product, it is very doubtful as to whether any of the kilns in operation today could show any better fuel economy than could be obtained from a well managed pot kiln.

For a kiln to use coal as fuel, and only natural draft, without steam, the writer considers a rather broad and short kiln stack about fifteen feet in height as representing the best modern practice. With the use of steam a slightly higher stack would be advantageous. Fifteen feet may be taken as a fair average. If stone is selected from the quarry down to about 1½-inch ring, or if the quarry be one naturally producing much small stuff, or if the stone be of a type which suffers disintegration in the burning, then it is probable that fifteen feet would be somewhat too much. On the other hand, treating a stone which would not pass or only barely pass a 6-inch or 7-inch ring, and using the smaller stuff for crushing, especially where the stone is of a type which does not disintegrate, it would be desirable to build the kiln from twenty to twenty-five feet in height. The use of wood fuel or some such system as the Eldred process, by which the flame is thrown further into the body of the kiln, would permit the use of five or eight feet additional.

The dimensions of such a stack for natural draft would be about as follows:

	Feet.
Height, grate bars to top	15 to 20
Diameter, inside of lining, at top	9
Diameter, inside of lining, 8 feet below top	7
Cross section, 5 feet above grate bars, round corners	4x7
Cross section at grate bars	4.5x6.5
Diameter, one foot below grate bars	6
Cooling chamber of metal, 7 feet deep, top diameter 6 feet, bottom	2.5

The total grate area, when coal is the fuel used, should not be less than two-thirds and need not be more than the area of the cross section of the stack space at that point.

There may be either two or four furnaces, preferably four—two on each side built symetrically in the center of the long dimension of the kiln and facing each other across the shorter dimension. If there is any underburned lime, it is always found in the center right between the fire arches which face each other. It seems that the flame and gas currents tend to diverge to right and left on entering the kiln rather than to penetrate straight through, since stone will be completely burned at a much greater distance from the fire on both right and left and stone in the center of the kiln which is much closer to the fire will be left with core in it. Round kilns, especially those of smaller diameter, when cooled off for repairs almost invariably show evidence of the greatest heat having traveled to the right and left or to the sides on which there were no furnaces.

When using a forced or induced draft the height may be made greater, with increased economy of fuel, as the gases escape cooler. The following dimensions will be found good:

	Feet.
Height, from grate bars to top	30 to 40
Diameter at top, inside lining	6
Diameter, 10 feet above grate bars, inside lining	7
Cross section, 5 feet above grate bars inside lining	5x7
Cross section, 2 feet above grate bars inside lining	5x7
Diameter, 1 foot under grate bars	6–6.5
Cooling chamber of metal, 9 to 12 feet deep, top diameter 6 feet, bottom	2.5

For natural draft the wide low kiln is recommended, because the larger cross section gives more space for the upward passage of the kiln gases, as well as a shorter trip through the twisting and devious passages to freedom at the top. This reduces the resistance to the movement of the gases and makes more of the natural draft, due to difference in temperature and height, available to aid complete combustion. Kilns of this type are shown in section in connection with the plans of the plants of the Woodville White Lime Company, Woodville, Ohio, on page 359, and that of the Scioto Lime and Stone Company, Delaware, Ohio, page 353. The Woodville plant which is using induced draft on these short kilns would no doubt obtain a much higher fuel efficiency if their kilns were twelve to twenty feet higher than they are today.

If kilns using only natural draft were built much higher, the gases leaving the top of the kiln would be cooled to such an extent that the draft would be insufficient to keep the fires in proper condition. The escape of these gases at a fairly high temperature means loss of heat, but it is unavoidable with natural draft. With the tall kiln, using forced or preferably induced draft, this heat loss is unnecessary since the kiln gases can in this case give up practically all of their heat to the descending limestone in the long upward passage. The tall kilns are shown in section in connection with the plans for the plants of the Standard Lime Company, Gibsonburg, Ohio, page 365, and that of Seneca White Lime Company, Fostoria, Ohio, page 349. The kilns of the Gibsonburg plant are well proportioned for coal and induced draft, but for the use of producer gas and induced draft a larger cross section at the firing arches would be desirable and result in increased capacity with no reduction in fuel efficiency. An induced draft system would probably increase the capacity of the kilns of the Fostoria plant, which is using natural gas as a fuel.

Kiln construction should be varied, with the size of material to be used, and with the method of firing adopted. In any case, the cooling chamber should be ample. If it extends seven to nine feet below the grate bars, and has as large a diameter as convenient, it will be sufficient for kilns with natural draft and capacities of sixty to eighty barrels in twenty-four hours, but for kilns using induced draft, and having capacities of one hundred and ten to one hundred and thirty barrels per day, this would be insufficient to properly cool the lime. In the latter case, twelve to eighteen feet of cooler will be desirable. The construction should be for the most part of metal and as much of the surface exposed to the air as possible, unless, as might well be done, the cooling chamber is lined by pipes or made double and hollow so that air supply for the furnace may be drawn through them and preheated, in which event the outside should be insulated and the length of the cooling chamber increased.

While Ohio probably produces lime as cheaply as any other state in the Union, no safe conclusion could be arrived at as to the best height of stack to use from practice as exemplified in Ohio kilns, since kilns ranging in height above the grate bars all the way from twelve to thirty feet, irrespective of firing conditions or size of limestone burned, can be found.

Many manufacturers could not show the detailed costs of production which would be the necessary preliminary to a safe comparison of kiln efficiency. The total lime cost was usually available, but other conditions vary so much that this total cost would not do as a basis of analytical study of kiln heights. There was obtained, however, sufficient evidence of a reliable character to amply justify the preceding suggestions, as representing the best Ohio practice.

A closer sizing of the stone burned and the use of smaller stone than is the present practice in Ohio seems to the writer to be very desirable.

The Fuel.—There are four natural fuels which may be obtained in Ohio for lime burning; these are (1) wood, (2) natural gas, (3) crude petroleum, (4) coal. In addition, various artificial fuels, or fuels which have undergone partial alteration from their natural condition, should be mentioned, viz: coke, reduced oil or petroleum residuum, and the various manufactured gases, chiefly producer and water gas, or a mixture of both. While the lignites and peat compressed into bricks are much used in foreign countries for lime burning and prove very satisfactory fuel for this purpose, it is not at all likely that they will ever be used in Ohio, since there is neither peat nor lignite in Ohio in commercial quantity and coals of higher grade are in easy reach to supply the fuel demands. Provided lignite or peat beds were located close to the kilns they might be used with economy, but these fuels would not stand a long freight haul.

Of these fuels, wood is the one best suited technically, and the one accepted by precedent. Unfortunately, the quantity of wood available for such crude manufacturing operations has become so reduced that only in a few favored localities can it be obtained. The lime plants in the Sandusky district have been for years employing steamboats to bring wood from Michigan and Canadian points, but are now driven by the constantly increasing prices and longer distances of the haul to use coal.

Natural gas was employed widely for a few years—1884 to 1890—but it soon became apparent that if gas were applied to such crude purposes there would be but little left of the local supplies for the more profitable uses of cooking and heating in homes and business buildings. In 1901, one plant in Springfield was still using gas, but has since ceased. While natural gas is an ideal fuel for this or any other purpose, it is certainly true that nothing but wasteful, almost criminal, extravagance would permit its use for burning lime, or brick, or making steam in a boiler. The natural gas supply should be preserved for domestic uses only. Within the last few years the supply from some of the largest gas fields of southeastern Ohio and West Virginia have been piped through to Toledo, passing through some of the lime territory. A few lime manufacturers have taken advantage of the availability of this gas for lime burning, although they realize that if it is used for all purposes they can only have it for a few years at most and must eventually go back to coal as their fuel. In 1905, one plant at Marion, one at Fostoria and one at Tiffin were using natural gas.

The plants using natural gas show a slightly higher fuel cost than those using coal, but the total cost per ton of lime produced and marketed is about the same, the labor saving with gas taking care of the small additional first cost of fuel. These plants will undoubtedly fall back on coal again in a short period of time.

Crude oil is another fuel of the same sort, though a much stronger case may be made for the legitimacy of using it for such purposes. In the first place, it is not volatile as is gas, and the supply is not escaping at every minute leak, nor is the visible supply decreasing at a parallel rate. Secondly, there are many crude oils which are of heavy nature and poor in the lighter hydrocarbons, like naptha and kerosene, and these are not profitably distilled. Others again are so rank with sulphur compounds that it is difficult to deodorize them and hence they are not desired for the still.

The use of these fuel oils in manufacturing operations is legitimate. Also, the demand for the lighter distillates, naptha and illuminating oils, is far in excess of the use for the moderately heavy lubricating oils and waxes, so that large quantities of these heavy residual oils are available for fuel at rather low prices. As they must be disposed of promptly, manufacturing industries offer the best market.

The use of crude oil, either raw or partly distilled, is, however, confined to a few localities only. It is not general, nor likely to become general in Ohio. The situation in Texas and southern California indicates that it may become a supply of considerable duration there.

The use of coal is a recent matter in limekilns and only became general under the stress of necessity. Old lime burners for many years protested that it could not be used successfully, and even now that it is the general resource, still claim that its results are far inferior to the wood to which they are accustomed. But, although the use of coal has required new methods of firing and some careful study on the part of burners, it is well proven to be a successful and desirable fuel if handled with skill. In fact, it is the only widely available fuel remaining, and its proper utilization is therefore a matter of prime importance.

Washed nut or slack coal is the usual form in which coal is applied to lime burning. At a number of plants "run of mine" is employed. At a few, coal and wood are jointly used. Good open-burning bituminous coal is referred to. Gas coal is preferable, but is not often available. Coals low in sulphur should be used. With natural draft, coking coals are very troublesome on account of the coal fusing and coking so as to cut off the draft.

Any lime producer, if asked what fuel will produce the best lime, will say "wood," and give as his reason, "it has a long flame." Natural gas has a long flame, but its calorific value is so high that great care is necessary not to overburn the lime. Aside from this, the amount of water produced in combustion is so large, that there is danger of fire-slaking, if everything is not exactly adjusted. Oil, vaporized by steam, comes nearer to duplicating the wood fire than any other fuel now in use for this purpose. The use of oil gives very large kiln capacities also. Lima oil, however, introduces sulphur compounds which are not advantageous. At any rate, the price of crude oils would ordinarily be prohibitive, and even if cheap enough there could be no guarantee that it would not shortly be pushed up to a very high price so that no one would care to take chances on putting in equipment for its use.

The introduction of some sulphur with coal cannot avoided, but it can be kept at a minimum by the use of coals low in sulphur or washed coals. Much can be done, however, in the way of improving the efficiency of coals, by selecting the right kind of coals, and by the proper manipulation of them during the burning, or by converting them into a gas of the proper composition for the best results.

Before we can decide how to modify our coal flame, to produce the best results, we must, if possible, determine the fundamental reasons why wood is the ideal fuel for lime burning. We must look to the composition of wood as ordinarily used and the nature of the flame produced by it for a solution of the problem. We may take air-dried wood as being made up of forty per cent. carbon, forty per cent. of hydrogen and oxygen in the proportions necessary to make water when completely burned, and twenty per cent. hygroscopic water.

This produces a long flame of low intensity. The hydrogen in the forty per cent. of hydrogen and oxygen above is necessary to the long flame. The twenty per cent. of hygroscopic water increases the length of the flame by cooling the gases and retarding rapid combustion, at the same time lowering the intensity of the flame by absorbing heat and transporting it to the stone. The above property of the flame, accompanied by the fact that the presence of the moisture or steam produced by burning wood materially lowers the temperature at which limestone is decarbonized, furnishes very good reasons why wood is the most desirable of fuels for this purpose.

In an attempt to duplicate the above conditions the best basis to work on will probably be that of the relation of hydrogen to carbon, since the water or steam can be readily supplied at the time of burning. This relation for the various fuels follows:

Table XXV—Composition of Fuels.

	Carbon parts.	Hydrogen parts.
Natural gas	100	35
Rock oil	100	19
*Wood	100	12.18
*Coal (bituminous)	100	6.12
*Coal anthracite	100	2.84
Producer gas (ordinary)	100	8 to 9

A gas made from bituminous coal, in a producer, supplying one-fourth of the required oxygen from steam and three-fourths from air, or using for one hundred pounds of coal two hundred pounds of air and twenty pounds of steam, thus making a mixture of producer and water gas, gives a product in which the rates of the carbon and hydrogen is 100 to 14.

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*From *Chemical Technicology Fuels*, Vol. I, p 58.

From the preceding, it is evident that the fuel nearest to the wood is the mixed water and producer gas. Since oil introduced with steam spray has proven very satisfactory, it is probable that a ratio of carbon to hydrogen ranging anywhere from that of oil to that of wood might well be used—between 10 : 2 and 10 : 1, with a preference for the ratio 10 : 2. The carbon monoxide (or carbonic oxide), which is the chief constituent of the producer gas, yields a moderately long flame of low intensity. By the introduction of a proper amount of steam with this gas, the conditions of wood burning should be closely duplicated, except that the introduction of some sulphur is inevitable, where coal is used in any form.

At Toledo, Ohio, in June, 1903, Mr. Charles Warner, of Wilmington, Delaware, in discussing the fundamental principles of combustion and draft as applied to lime burning, before the National Lime Manufacturers' Association, suggested that the relation of the fixed carbon to the hydrocarbons might be used as a guide in selecting the best coals for use in lime burning. He stated that other things being equal, the best results would be obtained from the coals lowest in fixed carbon and highest in volatile hydrocarbons. This might better be stated as follows: The coal which has the smallest ratio of fixed carbon to volatile carbon —i. e., that present in a volatile combination—will be best. He cites the low carbon content of wood as well as the desirable results obtained from gas coals, which are always low in fixed carbon, as supporting this suggestion. This suggestion is a valuable one, since the needed information is in a general way furnished by the proximate analyses of coals which are the kind of coal analyses usually available. This, of course, only gives a comparison of total volatile matter, as compared to fixed carbon, and in some cases might lead to very erroneous conclusions, especially if the ash were very high, since in such a case there might have been present water in combination or carbonates. Both this water and the carbon dioxide of any carbonates would appear as part of the volatile matter. If we had a determination of the calorific value of a coal, we could determine some of the suitability for lime burning, since a high calorific value indicates the presence of hydrocarbons, and not inert volatile matter in the volatile constituents of the coal. This, accompanied by the proximate analysis, would permit a more reliable estimate to be made of its probable value in lime burning.

We might, then, on this basis, consider a coal a very promising one which would answer the following requirements:

1st:	High calorific value or 12,600–14,400 B. T. U.	7,000–8,000 calories.
2nd:	High in volatile matter	32% or more.
3rd:	Low in fixed carbon	60% or less.
4th:	Low in sulphur	1.25% or less.
5th:	Low in ash	5% or less.

There are many coals that will answer these requirements.

Where the ultimate analysis of a coal is available, there is another ratio other than those previously considered, that is of some importance; i. e., the hydrogen should be high, and the oxygen low.

Use of Producer Gas.—Of course, with the use of a gas producer, some heat is bound to be lost by radiation. The closer the producer is to the kiln, the less will this loss be. It might even be built partially within the kiln walls, and with such a construction the loss due to radiation would be very small. Even with a detached producer, the increased efficiency of the fuel will more than counterbalance any loss due to radiation, in the opinion of the writer.

It would be premature to state definitely whether the gas producer in lime burning is a complete success as used today, or whether it introduces economy sufficient to counterbalance the large outlay consequent to its installation. Gas producer equipments have only been in use in this connection for a very few years. It is a very pertinent fact, however, that those who have installed producer plants have not abandoned them as yet, and the tendency is rather to increase the number of producers in use rather than to diminish them. One firm operating outside of Ohio, having used a producer for about a year, said: "We are not ready to either recommend or condemn the gas producer for lime burning." This firm found the fuel consumption about the same or a little greater than when using coal direct in the furnaces. They also could get increased capacity from the kilns for a day or two, but when it came to averages, month in and month out, they were apt to show slightly less capacity than formerly. This was due to the frequent delays caused by soot collecting in the flues, and to irregular working of the producer. Another manufacturer outside of the state, who has been using a producer a short time, feels that he gets very little increase in capacity, but saves a little on labor and has fully as good, if not greater, fuel efficiency. In Ohio, there are two plants equipped with gas producers. At one of these, a material increase in kiln capacity is claimed. Their fuel cost is very close to what is shown as the average for the better Ohio plants; i. e., from 3 to 3.25 pounds of lime for a pound of coal. The other plant shows small capacity per kiln, but a very high fuel efficiency. While this latter plant probably shows the highest fuel efficiency within the state on lime burning alone, they have not been able to reach five pounds of lime for a pound of coal, which is reported to have been obtained at the plant at Cedar Hollow, Pennsylvania, which was using the Eldred system of burning.

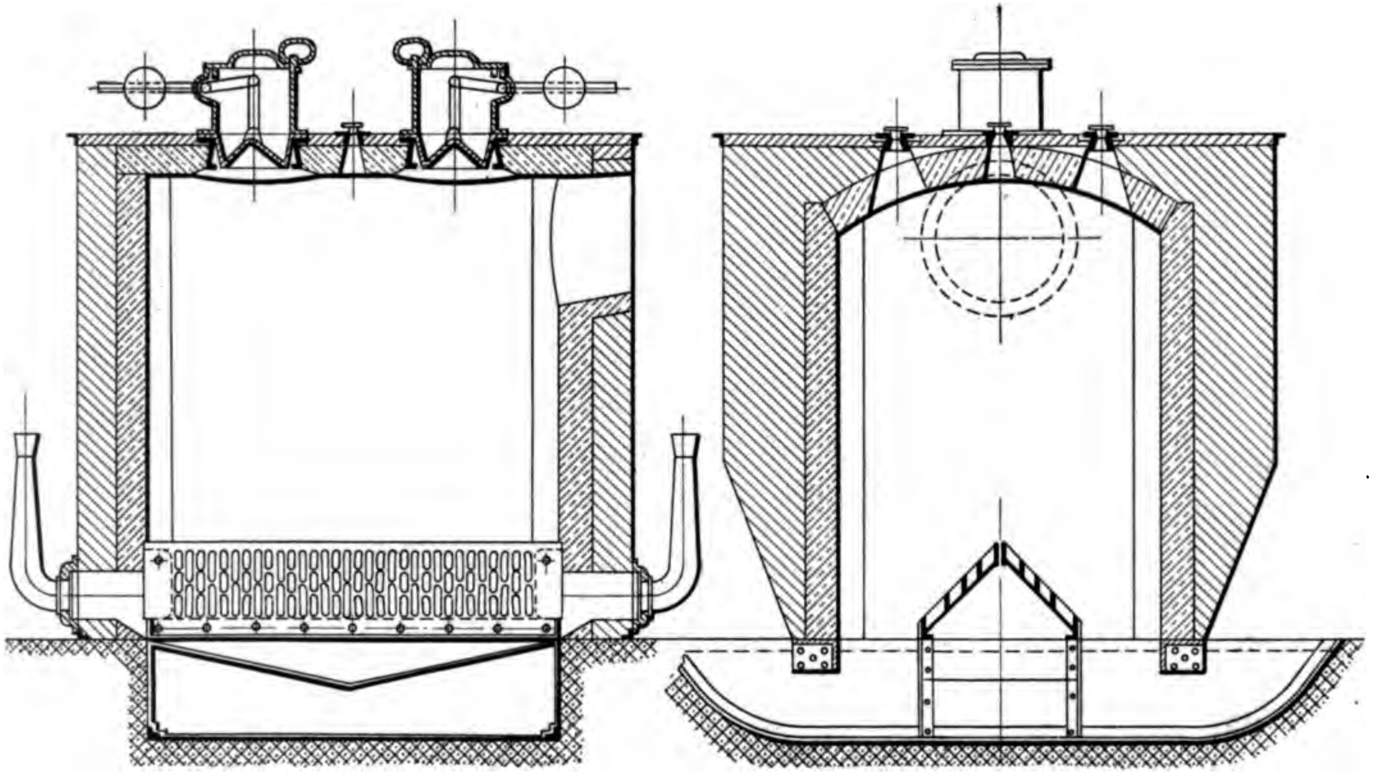
The following brief description and comment is abstracted from an address before the National Lime Manufacturers' Association, July, 1904, by Mr. H. P. Dodge, who was at that time manager of the Toledo White Lime Company. His subject was "Application of Producer Gas to Lime Burning."

At the time the address was made, he had had a little over a year's experience in the use of producers, and while he had met some obstacles and saw where mistakes had been made in the installation, he was still satisfied that it was a good thing and a paying investment. The capacity of the kilns were increased from 13,000 pounds per day to 15,500 and he expected to do better than this. The fuel cost remained about the same, but there was a saving of about 10 per cent. in the labor cost. The producers and installation were put in by Wm. Swindell and Brothers, of Pittsburg, Pa. Three producers built to convert eight to ten tons of coal into gas in twenty-four hours, were able to supply eight kilns, but did better work on five or six; that is, the fuel efficiency was greatest when the smaller number of kilns was in operation. The kilns farthest from the producer always showed the largest capacity. A stack sixty feet high by fifty inches inside diameter was found necessary for burning out the tar and soot from the flues satisfactorily, and this preferably should not be located very far from the producers. The firing ports entering the kiln should not be too small. Good, clean coal, high in volatile matter, was found best. Run of mine also had a preference as to size of coal to use. The expense of keeping up the producers was very slight.

The kilns are about 6 feet in diameter inside and the height from the top of the eye to the top of the iron work is 17 feet. They are rather short for gas firing. It was the intention of this Company to put on an induced draft system, using an exhaust fan, in which event these kilns would have about the right diameter, 6 to 6.5 feet, but for economy in fuel would lack about fifteen feet of the requisite height.

At the plant of the Standard Lime Co., Gibsonburg, which is the only other Ohio plant using gas producers, the equipment is somewhat different. Here one large producer built by the Duff Patents Co., of Pittsburg, to convert fifteen tons of coal to producer gas in twenty-four hours, is furnishing the fuel to operate seven kilns, and it is probable that they will try to operate two more with this one producer.

The kiln capacity is low, but the fuel economy is very good, compared to other Ohio plants using coal fuel. The kilns here are tall and narrow, being only about five feet in diameter at the fire arches. The stack is about thirty feet above grate bars. Only natural draft is used, except such forced draft as is obtained by the gas pressure and the pressure of the air for combustion, which is forced into the fire boxes at one side by a fan. There are but two burners to a kiln here. The kiln gases leave the kiln so cool that a man suffers no great inconvenience in walking across the top, at any point where the storage hopper is well filled The producer is located at one end of the battery of nine kilns, and the burn-off stack is close to it. It is customary here to burn out



Duff Patents Company's water seal gas producer.

the tar and soot from the conduits once a week. The location of the kilns, producer, and connections, are shown on the plans of this plant given on page 364.

The capacity of these kilns would probably be materially increased without decreasing their fuel economy, which is today above the average, if their cross section were increased to six feet at the fire arches, or perhaps better to five by seven feet. This plant is exceptionally well built throughout. No expense has been spared where an investment would produce economy in labor or fuel.

The illustration on page 280 is a portion of the firing floor, showing part of the gas main and burners:

In this case, it will be noted that the gas main comes beneath the burners.

The capacity of this plant could be greatly increased by the installation of another producer, and the addition of induced draft to their system, but it is a question whether this would give added fuel economy. It might even reduce that already attained.

Figure 21 shows another producer which, so far as is known, has not been used in lime burning, but is well established in other industries.

A number of devices are in use as the result of efforts to make the coal fire accomplish the same results as are obtained by wood firing. It is difficult to get as long a flame from coal as from wood, or, in other words, it is difficult to carry the heat as far into the kiln with coal as with wood, without overburning a portion of the lime. Since lime is a very poor conductor of heat, heating by conduction is very slow, and as a consequence one side of a stone might be overburned before the other side had even started to give off its carbon dioxide, if the firing were too intense.

One of the devices referred to is to introduce a jet of steam beneath the grate bars of the furnace. This serves a fourfold purpose:

First: It keeps the grate bars cool by absorbing heat from the first hot body it strikes, and thus prevents clinkers adhering to them, keeping the fire "open," or "free," as the firemen say.

Second: It forms a forced draft to some extent, since it enters the closed ash-pit under pressure.

Third: In its passage through the bed of coals it converts some of the glowing carbon into water-gas, and thus carries the center of combustion farther into the kiln

Fourth: The water vapor, broken up by the glowing carbon, which takes from the water its oxygen to form carbon monoxide, and leaves the hydrogen of the water in a free state, is again converted into water-vapor by combustion a little later This combustion of the free hydrogen generated from the water vapor takes place as soon as a sufficient quantity of pure air to supply the necessary oxygen to again form water

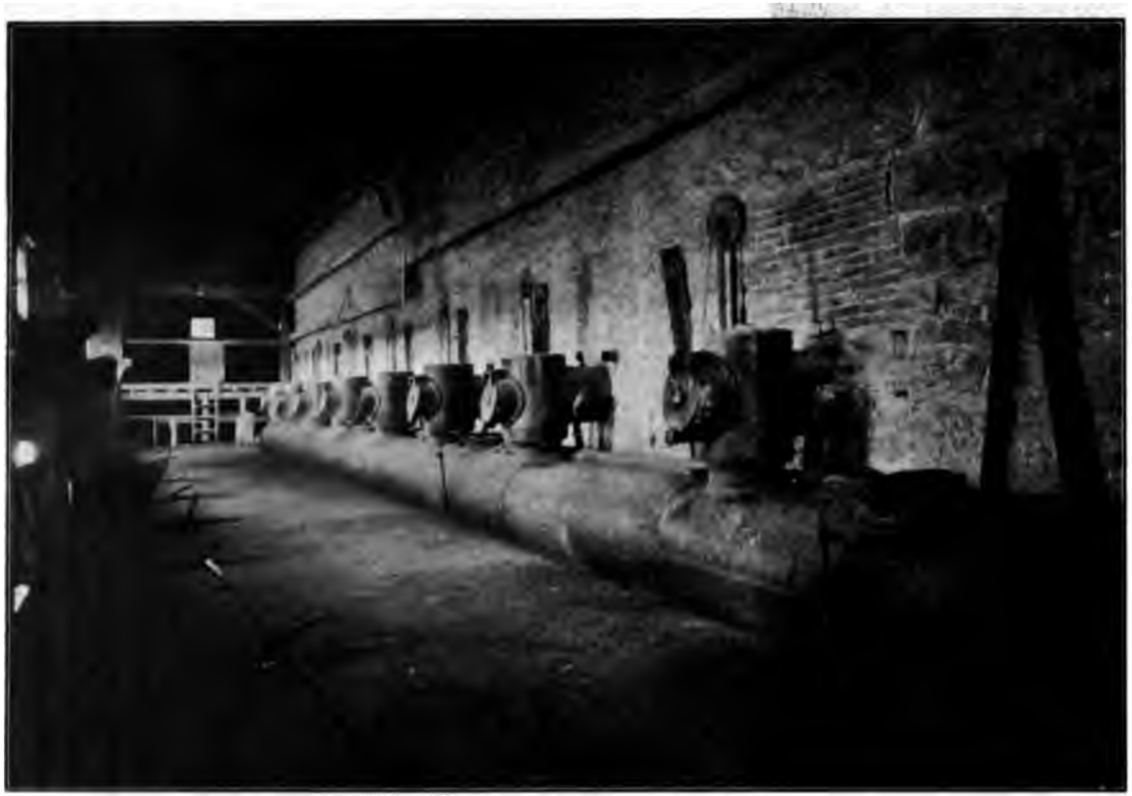


Figure 20.—Firing floor of the Standard Lime Company, Gibsonburg, Ohio, showing producer-gas mains and burners.

vapor is allowed to mingle with the furnace gases. Combustion will ensue immediately if the temperature is high enough to ignite the hydrogen, and this is always the case in the furnace of the limekiln. If the gases did not get into contact with each other until the cooler parts of the kiln were reached, they might not combine, in which case the steam would be occasioning a heavy loss of heat.

It must be understood that the introduction of water-vapor does not *make* heat—it simply aids in distributing the heat better. The decomposition of the water-vapor in the incandescent fuel bed of the firebox consumes heat very rapidly. It cools down the firebox, and prevents local overheating. Then, when the reburning of the hydrogen occurs later on, it merely gives back the same amount of heat that the decomposition of the water-vapor consumed. But, as this recombination takes place higher up in the kiln, it has the effect of spreading or lengthening out the zone of heat production, but not of changing the amount of heat produced.

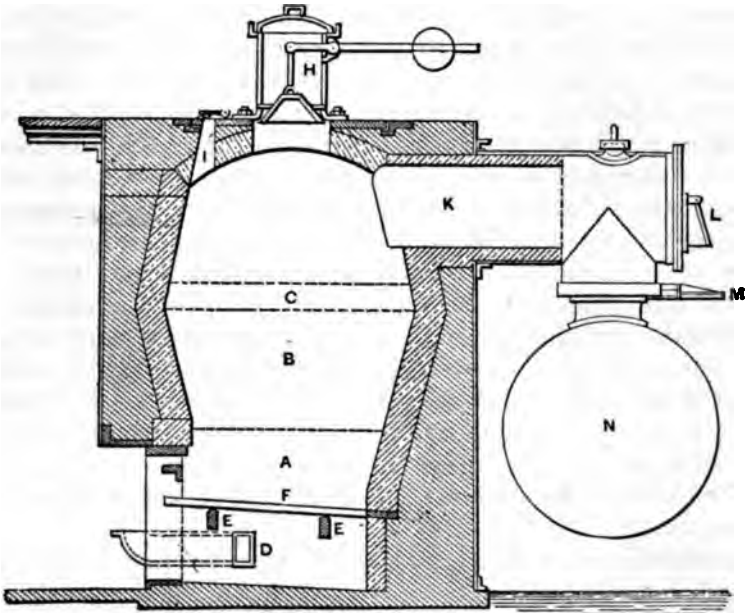


Figure 21.—Cross-section of a gas producer widely used in the metallurgical industries.

Furthermore, the water-vapor formed by the recombination of the hydrogen is formed at or near the point where the carbon dioxide is leaving the limestone. This is a very desirable state of affairs, since it has been shown that when steam or water is present, the carbon dioxide leaves limestone at a temperature of about 200° C. less than when steam or water-vapor is absent.

However, steam must be used with caution, for two reasons. *First:* If care is not exercised in its use, some arches are very apt to be melted down. *Second:* If too much steam is introduced, fuel is wasted as well as steam, since it is necessary to raise this steam or water-vapor to the temperature of the gases leaving the stack, which is usually greater than that of steam. If, however, the stack is of sufficient height, so that the heat is all absorbed by the stone, there would be no loss. But such a state of affairs would give very poor draft.

This introduction of steam under the grate bars virtually makes a water gas producer of the kiln furnace. The largest producers in Ohio have shown their wisdom by doing this. In order to duplicate the conditions of wood firing, it will be necessary to introduce water spray or steam into the firebox *above* the grate bars, as well as underneath them. While this is better than nothing at all, it cannot be handled so satisfactorily as with gas. The steam put in above the grate bars does not become so intimately mixed with the gases as they are burning, nor can the conditions be maintained with regularity, since the air supply is very irregular on account of the necessity of opening the furnace to introduce coal. A mechanical stoker, in an inclosed space, would help out with this procedure. It will probably be found advisable, or at least desirable, to use a fan on the top of the kiln, to produce a suction on the fire, rather than to force the gases into the kiln, on account of the reversal of the current when the furnace doors are open. A sufficiently strong jet of steam above the grate bars would serve the same purpose, acting as an air injector This, however, would probably require the use of too much steam for the good of the lime, as well as for economy in operation.

Another device is that known as the Eldred system. The patent upon which this is based will be described later. This is sort of a regenerative process of firing. A fan is connected up so that fresh air, or the kiln gases drawn from the stack, or a mixture of both (which is the usual procedure), may be forced into the ashpit. The practice is to force the fire with fresh air for a time, and then blow in kiln gases, which are still quite warm, then again force the fire by fresh air, etc., thus feeding the fire with a mixture of air and kiln gases, in such proportions as shall give the proper kind of fire. This alternate forcing with air and kiln gas first forms a very hot bed of carbon, which then gives its heat up to the inert kiln gases, which cannot support or promote much combustion, and a portion of the carbon dioxide is no doubt reduced to carbon monoxide, which burns to carbon dioxide again in the kiln furnace when it comes in contact with fresh air. These highly heated gases are then forced on through the stone and give up most of the heat taken from the glowing coals. The inert kiln gases simply act as a medium for carrying or transferring the heat from the fire to the stone in the kiln.

Several parties who have used this system state that it is the means of saving fuel. With careless handling of the fire, there would be some danger of having a little recarbonized lime, which would behave much the same as dead or overburned lime. In other words, the system requires skillful operation if more than ordinary results are to be obtained.

Systems such as the Eldred are gas producer systems, in a way, since in the passage of the kiln gases back up through the glowing carbon on the grate bars with a dearth of air, or the oxygen supplied with the air, a portion of the carbon dioxide (or carbonic acid) is reduced to carbon monoxide (or carbonic oxide), which is reignited when it comes in contact with sufficient air in the combustion chamber. In this way, the gas is carried well into the kiln before combustion is complete. This is a good feature of the system, since this gas gives a good flame of low intensity, and is not apt to overheat the lime, even when burning in actual contact with it.

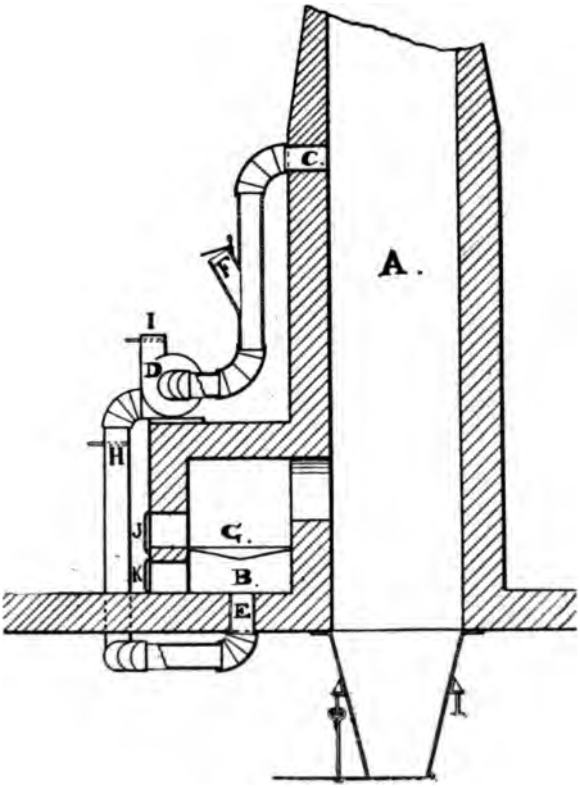


Figure 22.—Sketch illustrating the Eldred system. A, kiln shaft. B, ash pit. G, grate. E, duct from fan into ash pit. C, point at which kiln gases are taken off by the fan. F, fresh air valve. H, down pipe. J-K, door to fire box and ash pit.

A system of semi-gas firing, and a kiln constructed for that purpose, is described by Theodor Gerhard.* Since there is nothing of this sort in use in this country, we give the following translation by Professor A. V. Bleininger, of a portion of the article referring to the semi-gas fired limekiln used by him, as follows:

"There are four generators located around the circumference of the kiln, so that the gases pass directly into the shaft of the kiln, which is 2.9 meters in diameter at this point. A temperature of 1100 degrees C. to 1300 degrees C. is maintained within this zone, and for a height of 3 meters above it.

"In order to obtain the greatest heating value from the fuel, the air used in the formation of the gas is preheated by being drawn through the ash and cinder on an inclined basket grate, which has an arrangement for closing the space in front of it, and the air for combustion is preheated by the radiation from the generators and the cooling burnt lime, by drawing it in through a cast-iron heater in the center of the kiln shaft. This heater prevents the air from coming in contact with the cooling lime. The lime heats the air by radiation through the iron. The air only comes in contact with the lime where it meets the gases in the kiln shaft.

"This kiln is fired with gas produced from a mixture of Silesian small or nut coal (twenty-six to thirty per cent.) and an earthy lignite (seventy to seventy-four per cent.), in four generators, burning in twenty-four hours a total of 6.6 tons (of 2,200 English pounds each) of coal. The grate space is usually kept closed by the removable door *T*.

"The gases from the generators *B* pass through the mouths or firing arches *D* into the shaft filled with limestone before they meet the air necessary for their combustion.

"If it is desired to interrupt the flow of gas, the coal is burned down to the door and is raked away, the grate door is opened and the drawing door "O" is opened. In this way the draft on the generators is sufficiently lowered so that gasification ceases, and the air passes over the top of the fuel. Should any lime or limestone have fallen into the fire arches, it is now removed. At other times when this removal may be necessary, it is accomplished through the grates. If it is necessary to stop the flow of gas for any length of time, and hold the heat with closed doors, as would be the case over Sunday, the producers are fed with lignite only for several hours, and the fire banked by putting on a good covering of ashes; the ash door *G* and the doors *V* and *T* are luted tight, to keep out all air.

"In operation a small amount of air is admitted through peep holes closed with loose clay plugs into the generators above the glowing fuel, in order that sufficient combustion shall take place, to bring the gases

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***Thonindustrie Zeitung*, 1902, Nos. 11 and 14, pp. 103 and 144.

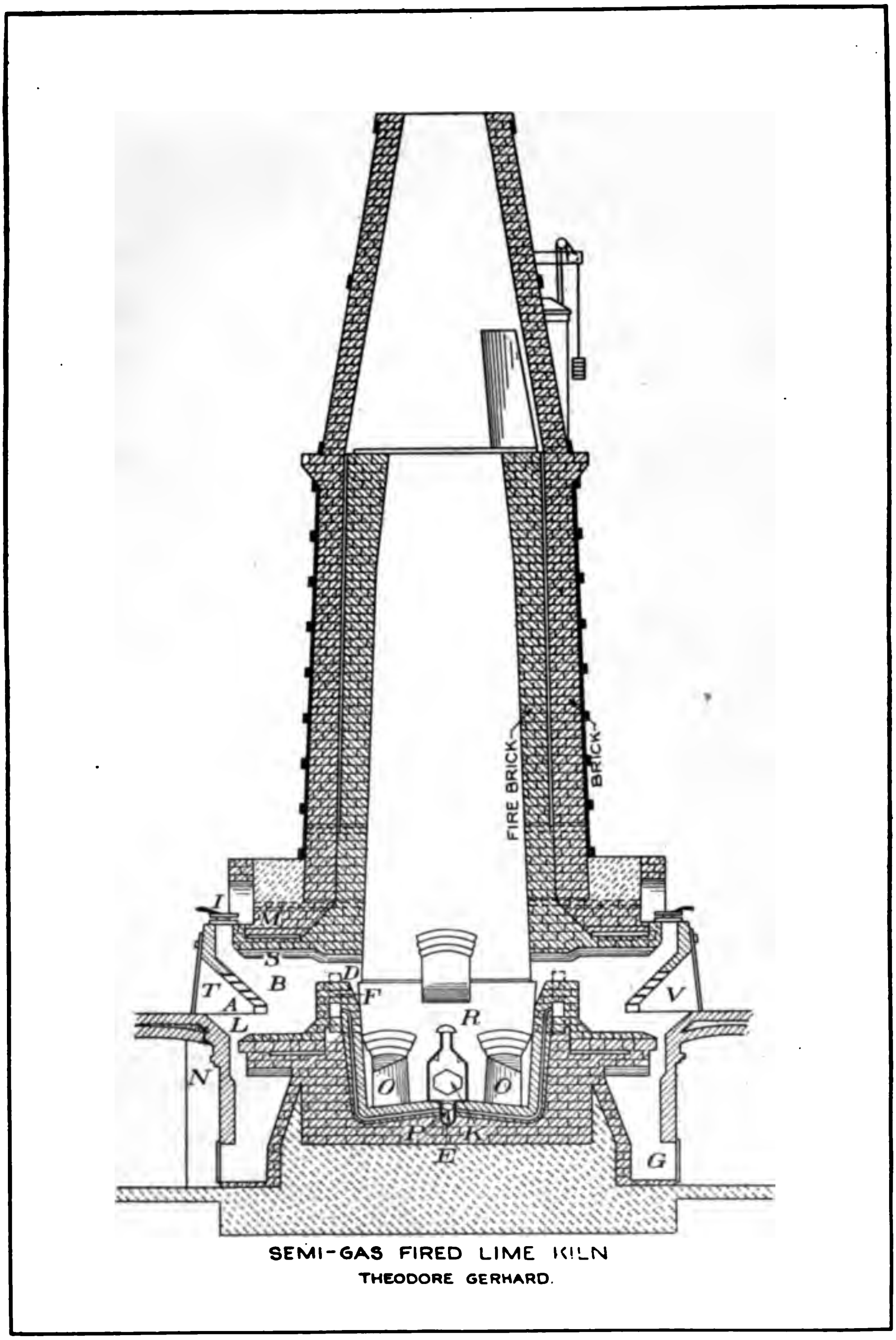

Figure 23.—Gerhard Lime Kiln.

to a higher temperature. These gases have in their production been cooled to about 800° C. Some carbon monoxide is here sacrificed in heating them up, but it is amply made up for by the more complete combustion within the kiln shaft.

The air inlet pipe *R* stands in the center of the kiln, and is covered with a cast-iron hood thirty-six centimeters (about fourteen inches) in diameter. The top of this pipe ends seventy to seventy-five centimeters (about twenty-eight to thirty inches) below the arches. This air inlet stands on top of the cast-iron heater *K*, which is sixty-five centimeters (about twenty-six inches) in diameter, and heats the air for combustion to from 200° to 500° C. The air is compelled to circulate against the walls of the heater, by means of sheet-iron baffle plates.

The air enters at *N* through seven rows of hollow brick in the generator walls and at *M* through the hollow arch and the second wall, uniting at the bridge wall *F*, which is cooled by their passage to the kiln wall through hollow brick and cast-iron pipe to the center of the kiln, where they connect with the cast-iron pipe supplying the air for combustion. Above the inlet openings of the generators, there are regulating valves attached to the central pipe, which are operated by the lever *E*, and a register rod at the front end of the pipe *P*, which is closed by an explosion cap.

"The more air entering the kiln, the farther toward the kiln walls will the flame be carried, until the flow of gas is shut off. With insufficient air, the flame burns only around the air inlet hood.

"The strength of the gas current is dependent on the kiln draft, the composition of the fuel and its size.

"With a charge of 5 cubic meters of limestone weighing 1.35 ton per cubic meter (2,970 pounds per cubic meter), with a size of stone ranging from 1 to 8 cubic decimeters (64 to 512 cubic inches) and not more than 15 centimeters (6 inches) thick, and one cubic meter of small stone weighing 1.3 ton (2,860 pounds) ranging in size from 0.25 to 1 cubic decimeter (1 to 64 cubic inches), the free air and gas space in a horizontal cross section of the kiln will be as follows:

1 cubic meter of limestone = 2280 kilograms.

$$2280\left(-\frac{5\times1.35+1.3}{6}\right)\times\frac{100}{2280}=41.15\%\ \text{air space.}$$

"That is, with a stack opening of 2.27 square meters, there will be an open space when filled with this limestane of 0.934 square meters.

With thirty-three per cent. of small stone, this space would be 0.943 square meters. The stack opening is 0.344 of the greatest cross section of the stack, which is 6.6 square meters.

The shaft space below the arches=	11 cubic meters
The shaft space above the arches=	39 cubic meters
Giving a total kiln space of	50 cubic meters

"The inside grate surface is 2.22 square meters, or 0.336 of the shaft section, wherefrom 55% is taken by the openings for stoking and clinkering. The grate is inclined at an angle of 40°. The layer of coal on the grate is 33 centimeters (about 13 inches) thick. The arch openings are 1.2 square meters cross section, or 0.185 of the kiln section at that point. The valve of the central air inlet is held after the draw at 44 square centimeters for five hours, and is then opened to 67 square centimeters. The draft, measured at the generator peep holes, was 4.5 to 5.1 millimeters water column; at the explosion caps, 2.9 to 4.1 millimeters; at the air inlet dampers, 0.7 millimeter.

"The procedure in starting the kiln is as follows: On starting the generator a provisional horizontal grate is built up in front of the fire bridge. All four generators are first fired with a free flame for twenty-four hours, and only when the shaft shows sufficient bright-red heat is gas firing begun. As soon as 300 to 320 hektoliters of coal have been burnt, the drawing of lime is begun. Some coal is also charged together with the stone in the beginning. Before starting the fire, the central air valve is opened to 8 square centimeters, and is left in this position up to several hours before drawing the stone, when it is changed to 44 square centimeters. This avoids gas explosions, and the lime forms a nearly horizontal layer at white heat at the height of the mouth holes where it will hang, until the lime is drawn rapidly through the four draw holes. Before drawing the burnt lime, the coal is allowed to burn down to the cleaning door. The white-hot coal in the generator decomposes any steam still rising, and changes any $Ca(OH)_2$ forming in front of the mouth-holes to CaO. When the kiln is finally in operation again, the air is heated to 500° C. in daytime by placing upon the upper pipe end *M*., outside, a sheet-iron cup with a round opening 2.5 centimeters in diameter. At night, the air is preheated only to 200° C. by carrying the air only through one generator wall, and closing the upper opening *M* with a loose clay stopper. The opening of the central air inlet is increased to 67 square centimeters only after two weeks. All the burnt lime must never be drawn at once. The coal is weighed out daily.

"For the burning of one ton of limestone, there was required 0.483 tons of coal and lignite mixture, made up as follows:

	Parts.
Small high-grade coal	0.275
Screened lignite	0.295
Lignite slack	0.430
Total	1.000

"With limestone containing 16% small stone, the kiln capacity was 11.73 tons (of 2,200 pounds each).

"The analysis of the coal and lignite mixture was as follows:

Carbon (C)	44.85
Hydrogen (H)	3.45
Oxygen (O)	5.38
Hygroscopic water (H_2O)	22.34
Sulphur (S)	2.77
Ash	11.21
Total	100.00

"The limestone contained 37 to 42% of carbon dioxide and 2% water. The coal mixture burned per minute was 5.266 kilograms. The theoretical amount of air required for complete combustion of one kilogram of this coal mixture is 15.717 kilograms, which amounts to 4.414 cubic meters at 0° C. Therefore, each minute there will be required 5.266 x 4.414 = 23.244 cubic meters of air at 0° C., or at ordinary temperature (20° C.) it would be 24.95 cubic meters. This amount must pass into the kiln each minute. The calculated calorific value of this coal mixture is 4,000 calories."

He also gives the available heat as being 3,842 calories, but does not specify under what conditions this is the case. He also calculates what he calls the pyrometric heat effect (probably calorific intensity) of his fire, with 100% air excess, and finds this to be 1209° C. He says, however, that complete combustion is obtained with a much lower air excess. The temperature of the shaft was determined by enclosing pyrometric alloys in the limestone.

When using cold air in the central air passage, and the following mixture of fuels:

	Per cent.
High-grade nut coal	44
Earth lignite, nut	26
Lignite, run of mine	30

the stack temperature was found to be 1100° C. Under these conditions the kiln capacity was 12.91 tons in twenty-four hours, with a fuel consumption of 0.445 tons per ton of lime produced. It is customary to draw but twice a day.

It is probable that eventually gas producer systems of some sort will be installed at all the larger plants. It also seems probable that it will not be a great while before the limestone screenings, which are a drug on the market at most points, will be burned in a rotary kiln, fired by producer gas, and the lime thus produced will be hydrated for the market.

In determining the relative value of fuels, three things must be considered:

First: Quality of the product.

Second: Cost of fuel per unit of lime burned.

Third: Cost of labor per unit of lime.

The practice of Ohio lime burners furnishes the following data:

	Barrels of 185 pounds net each.
One cord of hard wood (air dry) will make	25 to 30
One barrel of Lima oil will make	25 to 30
1,000 cubic feet of Ohio natural gas	2 to 2.5
One ton of good bituminous coal, burned with natural draft, will make	30 to 35
One ton of bituminous coal, using steam under the grates, forced or induced draft	40 to 45
One ton of good gas coal, in gas producer	35 to 45

The cost of labor will be about one-half cent per barrel greater when using wood, than for oil or gas. When using coal with natural draft, the labor cost is one-fourth to one-half cent per barrel of lime produced, over that for gas or oil; with forced draft and steam, the labor cost is slightly less, but to this must be added cost of steam and power for blowers, which hardly brings the cost of labor and additional power up to that for labor alone with natural draft.

At first glance this last statement, that the labor cost plus cost of power for blower and cost of steam, is less than labor cost alone with coal and natural draft, seems inconsistent. The lower labor cost per unit of lime is due to the increased capacity of the kiln. The same labor cost per day handles more lime.

The statement made above as to cost per unit of lime is not affected by kiln capacity, except in this, that the investment per unit of lime will be least with the most efficient fuel.

From the above statements anyone can figure which is the cheaper fuel to use in any particular locality, when the cost of the various fuels is known.

Kiln Capacities.—Taking the capacity of a kiln fired by coal and natural draft as a basis or starting point, with wood firing the capacity will increase about twenty per cent.; with oil and draft forced by steam and under good management, about twenty-five per cent. increase may be obtained, this method showing the largest capacity of any so far tried in the state. With natural gas, the same kilns produce fifteen to twenty per cent. more lime; with coal and draft forced by steam, ten to twelve per cent. increase is usually attained; when coal with a little steam, aided by mechanically induced draft, is used, a gain in capacity of fourteen to eighteen per cent. is usually recorded.

Kiln capacities as exemplified by Ohio plants working under widely different conditions vary from 60 to 100 barrels per day of twenty-four hours. Claims are made of capacities of 125 barrels and even more. These results are no doubt the result of spurts, and at the expense of a much larger fuel consumption than is demanded by these kilns when run normally, with the usual production of about eighty-five barrels per day of twenty-four hours. The majority of the manufacturers (not the majority of the kilns, however) are working with a kiln average below eighty barrels. The majority of the kilns operated are producing on an average over eighty barrels per day. Some of the larger manufacturers are actually getting for a good proportion of the year a daily output per kiln of eighty-five to ninety-five barrels of lime, weighing 185 pounds net, or 200 pounds gross, in barrels. There are a number of plants in the state where both capacity and fuel economy could be increased at a comparatively small cost.

Mr. W. S. Sutliff, who has had about thirty years of experience in the lime business, and used almost all kinds of fuel and is a close observer, says, with regard to kiln capacities, that he has obtained the following outputs, per twenty-four hours, with kilns when using different fuels:

Fuel.	Barrels of 185 pounds.
Lima oil	120
Natural gas	100
Wood	115
Coal	78

He further states that the capacities could not be kept up to show that amount for a long period of time, and that such outputs are usually obtained at a sacrifice in fuel economy and excessive kiln repairs. The delays caused by these repairs must also be considered.

Quantity of Fuel Used.—The range of the amount of fuel burned per unit of lime produced is not so wide as was the case with kiln capacities. The fuel consumption for almost every good plant in the state for the burning of one net ton of lime will fall between 575 and 625 pounds of good bituminous coal. When the continuous or Hoffman kilns were in use, 400 pounds of coal would in these kilns produce a net ton of lime. These kilns have been practically abandoned for two reasons; i. e. the quality of the lime produced was not the best, and the labor cost was excessive. There have been three such kilns in the state. One is torn down; the other two still stand, but are idle.

The fuels used come from the Pittsburg field, southeastern Ohio and the West Virginia districts. The gas coals, or those high in volatile matter, are selected. They must be free-burning coals low in sulphur.

Fuel Costs.—The fuel costs vary somewhat, also. In some cases high fuel cost is easily explained by the type of kiln and method of operation, or by the fuel used.

A plant burning high-calcium lime, with natural draft, rather short kilns, and coal as fuel, had the following costs for total fuel for plant, including power:

Cost per ton quicklime, 1903	87.14 cents
Cost per ton quicklime, 1904	72.00 cents
Cost per ton quicklime, 1905	63.14 cents

In 1905, considerably more fuel was used for power than formerly.

In another plant, using round kilns of medium height, six feet in diameter at fire arches, natural draft, using wood and coal for fuel in 1904, and natural gas in 1905, gave the following costs:

Cost per ton quicklime, 1904	50.00 cents
Cost per ton quicklime, 1905	56.00 cents

This cost is for fuel for lime burning only.

At another plant, using very high round kilns, whose diameter at the fire arches was 5.5 to 6 feet, with natural draft, and natural gas fuel, gave the following:

Cost per ton quicklime, 1905 with natural gas	64.4 cents
Cost per ton quicklime, with coal, in former years	72.0 cents

At another plant, using producer gas, in tall round kilns, of a diameter at the fire arches of 5 to 5.5 feet, running under natural draft, the following average fuel cost for 1905, for burning of lime only, was obtained.

Cost per ton quicklime, 1905	56.6 cents

Same kilns in former years with coal as fuel showed a much higher fuel cost.

Another plant, using producer gas, short kilns, elliptical or oblong in cross-section at the fire arches, about five by seven feet, under natural draft, showed as follows:

Cost per ton of quicklime, 1904	66.6 cents.

Same kiln with coal, former years, at least 10% greater cost.

Another plant, using coal and induced draft, short kilns, oblong at fire arches, about five by seven feet, showed a cost per ton of quicklime, in 1905, of 61.4 cents.

At a very large plant in the state, where accurate figures were not available, using circular kilns above medium height, six feet in diameter at fire arches, and steam under grates, natural draft, the management stated they had been running a number of years at a fuel cost of fifty-five to sixty cents per ton of lime.

All of the plants, except the first one, are burning dolomite, and all of the figures given, except for the first plant, are fuel for lime burning only. In order to bring the figures of the first plant cited to the same basis as the others, we will deduct one-fifth of the total fuel cost, which has been shown to be a fair average to represent the fuel used in power. This gives:

Cost per ton quicklime, 1903	69.7 cents
Cost per ton quicklime, 1904	57.6 cents
Cost per ton quicklime, 1905	50.5 cents

These figures suggest several things, when the circumstances surrounding this plant in the different years are known. In 1903, fewer kilns were in operation, and those that were in operation had but two large furnaces. In 1904, more kilns were in operation, and some of them had four small or narrow furnaces, instead of two larger ones. The four small furnaces had a larger total grate surface than did the two larger ones. In 1905, still more kilns were in operation, and the running was more continuous. In 1905, practically all of the kilns were equipped with the four small furnaces. This seems to speak very favorably for four small or narrow furnaces, instead of two larger ones, where coal and natural draft are used. Another interesting point is that this plant working under conditions which, in comparison with plants working on dolomite, should show a higher fuel cost than many of them, shows a lower cost. It thus substantiates the statement made by nearly all lime burners who have had experience with both types of lime, viz: that it always takes more fuel to burn dolomite limes than it does to burn the high-calcium stone. This latter would be a very logical supposition from the nature of the case, since it is very likely to require more heat units to break up the mineral dolomite, which is a definite chemical compound, consisting of a double carbonate of calcium and magnesium in molecular ratio, than it does to break up the simple carbonate of magnesium. The heat of dissociation of calcium carbonate has been determined, but, so far as the writer is able to find out, no such determination has been made for the mineral dolomite. Since dolomite is a mineral of definite chemical composition, we cannot safely assume, as was done by one writer, that because it analyzes about forty-four per cent. magnesium carbonate and fifty-six per cent. calcium carbonate, we can take the heats of decomposition of these two distinct minerals in these proportions and calculate the heat required to drive the carbon dioxide out. If dolomite were a simple mixture of calcite (calcium carbonate) and magnesite (magnesium carbonate), we might safely assume the above to be true.

This writer, by calculation on this basis, shows that only about 0.75 as much fuel would be needed to burn dolomite to lime as would be needed for calcite on the calcium carbonate.

Temperature of Burning.—The temperature of burning is a very important factor, both in the quality of the product and in the economy of the production. Economy in manufacture requires that the temperature of burning should not be greatly beyond that needed for the complete removal of the carbon dioxide (CO_2). The statements made elsewhere in this article with reference to the time required for slaking limes burned at different temperatures, shows clearly that the sensitiveness or quality of the lime is materially affected by any very great overheating, since it required twice as long to slake lime burned at 1050° C. as it did that burned at 950° C. However, some writers say that some limestones will, under normal conditions, require a temperature greater than 1000° C. for the complete expulsion of carbon dioxide. Herzfeld found that, in the examination of 64 different limestones and marbles, a temperature beyond 1040° C. was required by none of them, and that a lower temperature was sufficient for the complete expulsion of carbon dioxide in most of the cases examined.

It has also been shown that for each temperature the evolution of carbon dioxide from calcium carbonate remains stationary for each different pressure, and that the reaction is reversible. That is, if calcium carbonate were placed in a tube, and kept at a certain temperature, the carbon dioxide could be drawn out from the limestone, or cause it to be absorbed, by simply raising and lowering the pressure in that tube. Le Chatelier* in determining the dissociation tension of calcium carbonate showed this very clearly. The following table shows the temperature at which calcium carbonate breaks down at different pressures.

Table XXVI—Dissociation of Calcium Carbonate.

Pressure.	Temperature.	Pressure.	Temperature.
27 millimeters mercury.	547° C.	289 millimeters mercury.	745° C.
46 millimeters mercury.	610° C.	678 millimeters mercury.	810° C.
56 millimeters mercury.	625° C.	753 millimeters mercury.	812° C.
205 millimeters mercury.	740° C.	1333 millimeters mercury.	865° C.

Since 760 millimeters of mercury are considered standard conditions for atmospheric pressure, 812° would be about the lowest temperature that would drive off any of the carbon dioxide in the ordinary way. A fact of value to the lime manufacturer is shown here, viz: if he is running his kiln under reduced gaseous pressure in the stack, as would be the case with induced draft. or suction on the top of his kiln, he will not need to make his limestone so hot in order to eliminate the carbon dioxide as he would have to do if the pressure in the kiln were the same as the atmosphere outside. Also, that a higher heat will be necessary to do the work if he is operating under increased kiln pressure, as is the case when the draft is forced from below. When steam is used to force the draft, he loses a portion of the beneficial effect of steam due to this property of the limestone.

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*Compt. Rend. 102, 1233 (1886).

The decomposition of limestone is greatly accelerated by the presence of steam. Herzfeld, who made extensive experiments with calcium carbonate and superheated steam, proved that a high grade porous calcium oxide could be made from the carbonate with superheated steam. The following table shows the behavior of calcium carbonate in superheated steam:

Table XXVII—Herzfeld's Results.

Temperature.	500°C.	650°C.	680°C.	790°C.
Per cent. of calcium oxide in limestone burnt in steam	0	7%	23%	100%
Per cent. of calcium oxide in limestone burnt in air	0	0	0	37%

The same author states that a temperature of 1040° is usually necessary for the complete decomposition of limestone, so that steam shows a gain of 250°, which would mean a large saving in manufacture. This is probably one reason why wood shows such great efficiency in lime burning, since it throws into the kiln large quantities of superheated steam. This table also shows that at temperatures below that at which the expulsion of carbon dioxide is complete, a portion only will be given up, and that the amount of carbon dioxide given off will be stationary for any given temperature and pressure.

Calcium oxide at high temperatures takes up carbon dioxide with great avidity, as may easily be shown by heating calcium oxide to redness in a glass tube, through which large volumes of carbon dioxide are passed. The external heat can be removed, and the calcium oxide will continue to glow and throw off heat until it has all burned back to the carbonate. Therefore, any increase of pressure in the kiln, or any falling of the temperature, will cause the reabsorption of carbon dioxide.

The presence of impurities tends to lower the decomposition temperature, and at the same time makes the lime much more sensitive to overburning.

R. W. Nauss, as a result of experimental work with calcium carbonate, clay and quartz, done in connection with a thesis for graduation at the Ohio State University, arrived at the conclusion that calcium carbonate, in the presence of clay and silica, begins to break up between 610° and 650° C.; before 700° C. is reached, the evolution of carbon dioxide is quite marked; at 1000° C., it is practically complete.

We find nothing at all, however, with reference to the behavior of dolomite.

Experimental Investigations, Made by the Writer.—In order to get at what is needed to bring about the best results in the way of lowering the temperature of lime burning, and thus introduce fuel economies, the gases must be analyzed, and the kiln temperatures, as they are maintained in present practice, must be measured.

In order to gain some more accurate knowledge of the effect of temperature in lime burning, a series of substances, comprising pure limestone, pure dolomite, pure magnesite, chemically prepared carbonate of calcium, chemically prepared carbonate of magnesium, and a mechanical mixture of chemically prepared carbonates of calcium and magnesium, in the dolomite ratio, were heated at various temperatures under accurately controlled conditions, and the effect of this heating was then studied by slaking the product in a calorimeter. The heat given off is a measure of the perfection of the process; i. e., either underburnt or overburnt lime shows lower results in the quantity of heat evolved, and in the rapidity of the heat development.

All of the limes tested were burned by Professor A. V. Bleininger, in connection with his work on portland cement. A calibrated Le Chatelier pyrometer was used to determine all temperatures. The burning was for the most part done in a gasoline-fired muffle, and at atmospheric pressure. The balance was done in an upright muffle kiln, using wood fuel. Some limes burned in this same kiln, with coal as fuel, showed so much sulphur that they were discarded. The limestones and dolomites were in a coarse powder when burned and were kept at the designated temperature a little over one hour.

The heats of hydration given in table XXVIII are the number of gram calories of heat developed by one gram of the sample. They were determined in a calorimeter of the type shown in the illustration, in which the temperatures could be easily read to less than 0.01 of one degree. One hundred cubic centimeters of water was used, and from 0.5 grams to 2 grams of the lime to be tested. The amount of lime used was regulated to give about one degree rise in temperature.

The results given in table XXVIII are for the most part averages of a number of results, which were usually within a few calories of each other.

Some magnesite was also burned and an attempt made to determine the heat of hydration, but the results were unsatisfactory; no opportunity to duplicate the burning was found, so that the results could not be checked; hence, we have no confidence in them.

No burning temperature was found at which magnesite seemed to develop any considerable heat, and all samples of calcined magnesite showed effervescence with acid, when tested for carbonates later.

The heat developed from properly calcined magnesite should at some temperature of burning be the same as that for chemically-prepared magnesium carbonate, but at no point in the experiment cited was it more than one-third of this. The temperatures at which the maximum heat was developed are from 100° to 200° higher than was shown to be needed by artificially prepared magnesium carbonate. This note is given here in the hope that some one will take up this problem and work it out thoroughly.

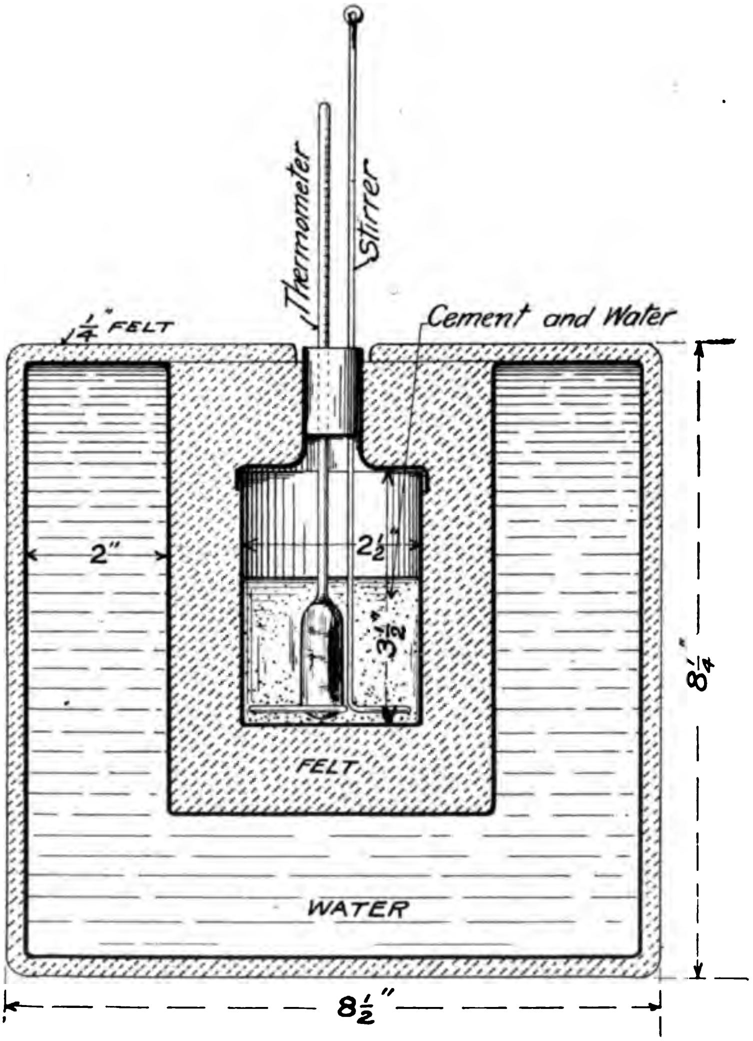

Figure 24.—Showing calorimeter used in studying heat of hydration of lines.

Table XXVIII—Heat of Hydration in Gram Calories.

Burning temperature °C.	Limestone 99.5% $CaCO_3$.	Dolomite $(CaMg)CO_3$.	Chemically prepared $CaCO_3$.	Chemically prepared $MgCO_3$.	Mechanical mixture of chemically prepared $(CaMg)CO_3$.	Magnesite $MgCO_3$.
400	....	00	....	76.	....	....
500	....	00	....	109.5	28.5	....
550	....	....	....	....	20.8	....
600	....	8.3	....	125.	15.5	12 (?)
650	....	....	....	....	4.1	12 (?)
700	....	4.7	....	7.7	4.7	41 (?)
750	....	9.5	....	....	8.3	6 (?)
800	34.5	10.2	9.5	....	95.3	38 (?)
850	73.8	58.8	70.2	10.1	125.6	8 (?)
900	175	104.8	220.	7.1	137	5 (?)
950	257	130	250.	....	136	....
1000	252	128	246.3	....	129	12 (?)
1050	252	131	....	....	123	....
1100	252	131	....	....	123	....
1200	247	126	195	....	137	....

The table presents an array of facts: *First:* That limestone and dolomite both lose a little carbon dioxide in one hour at 800°.

Second: Both ground limestone and dolomite lose all their carbon dioxide in one hour at 950° C.

Third: There is no material change in the amount of heat given off by the oxides on hydration up to a burning temperature of about 1200° C., but at 1200° C. a small portion has been burned so hard that it is no longer sensitive to the action of water.

Fourth: No heat of hydration for the magnesium oxide in dolomite is shown at any burning temperature. This suggests that with dolomite the carbon dioxide combined with the magnesia does not begin to go until that with the calcium starts, and that this temperature is sufficient to render the magnesium oxide practically inert to the action of water. This is just what would be expected if dolomite is a chemical compound, a double molecule of calcium and magnesium carbonate, and not a mixture of two carbonates.

Fifth: The behavior of a mechanical mixture of calcium and magnesium carbonates does not behave like dolomite, but when burned at 500° develops some heat due to the hydration of magnesium oxide, and at 650° the magnesium oxide has reached a state of overburning, which prevents its taking up water of hydration, while the calcium carbonate has not yet lost any carbon dioxide. The calcium oxide reaches its maximum activity at 900° to 950° C.

Sixth: Chemically prepared magnesium carbonate loses considerable carbon dioxide when heated for one hour at as low a temperature as 500° C., and reaches a maximum degree of hydration when heated for one hour at 600° C., and at 650° to 700° C. it has suffered a change which prevents hydration, or has rendered it so slow as not to be detected in any but the most exact of calorimeters. It requires about four hours to hydrate one gram of magnesium oxide (MgO) in 100 grams of water at 17° to 20° C., when burned at 600° C.

Seventh: Calcium oxide apparently has a wider range of burning temperature at which it is sensitive, than has magnesium oxide, and it would probably require temperatures of 1600° to 1800° C., before it would be rendered entirely inert to the action of water.

The chemically prepared magnesium carbonate was a basic carbonate, carrying about 10% of magnesium hydrate. This accounts for the heat of hydration given for the sample burned at 400° C., since the hydrate loses its combined water below that temperature.

The specific gravity test was also applied to the limes produced in these experiments, to see if the data thus obtaned confirmed the results of the heat of hydration.

Table XXIX—Specific Gravity of Limes Produced in Experimental Investigation.

Burning temperature °C.	Chemically prepared $CaCO_3$.	Chemically prepared $MgCO_3$.	Limestone 99.5% $CaCO_3$.	Dolomite $(CaMg)CO_3$.	Magnesite $MgCO_3$.
400	....	....	....	2.6	....
500	....	2.36	....	2.56	....
550	2.63	....	....	....	2.86
600	....	2.62	....	2.7	....
650	2.59	....	....	....	....
700	....	2.45	....	2.7	....
800	2.67	....	2.69	2.73	....
850	2.71	....	2.83	2.94	....
900	2.80	3.2	3.16	....	....
950	....	....	3.33	3.16	....
1000	3.18	4.6	3.28	3.20	....
1050	....	....	3.03	3.20	....
1100	....	....	3.37	3.33	....
1200	....	....	3.00	2.96	....
1400	....	....	2.86	....	....

The Measurement of Temperatures in the Kiln.—In the use of heat, it has been found by chemists, engineers and men in charge of industrial operations, that some definite control or means of accurately measuring or duplicating temperatures is desirable and in many cases absolutely necessary. In some industrial operations it is necessary to know the temperatures to within a few degrees of accuracy for the success of the operation.

In the earlier development of the iron and steel industry, temperatures were only measured with the eye, as is the case in the manufacture of lime today. The iron industry early recognized the necessity of more accurate control of temperatures, and with the introduction of instruments of various types for this purpose, new products were developed, which were before impossible.

In view of the fact that the lime manufacturers have finally reached an era of improvement and development, and are on the lookout for every means which might introduce a new economy, or an improvement in the quality of the product, it would seem that they might now be ready to introduce an innovation in the way of an accurate temperature control, if the means were at hand, whereby these temperatures could be readily measured, and duplicated within a reasonable degree of accuracy, when the proper temperature was once determined for the best possible quality of lime from the stone burned. Present practice in this respect is very crude, since everything is dependent on the trained eye of the burner. It is hardly likely that with the high red to white heats, to which limestone must be brought for this purpose, that any man's eye, no matter how well trained, can tell whether he is one, two or three hundred degrees beyond the temperature at which the white heat is produced. If the proper temperature was one which was just marked by the change rom a dull to a glowing red or from a glowing red to a white heat, it might be more accurately observed and marked by the naked eye.

Every lime manufacturer is familiar with the undesirable qualities produced by overburning; i. e., by subjecting the stone to an excessively high temperature. All are familiar with the inconvenience and loss due to burning at insufficient heat, which causes the production of core, which is dead waste.

The only reason why fairly good limes have been produced by the crude methods of control which are in vogue today, is that the range of temperature between which carbon dioxide is eliminated and the point at which the lime begins to show the effect of overburning is comparatively wide. This range is approximately 200 degrees centigrade. The carbon dioxide begins to go off slowly, somewhat below 900 degrees C., but even at 900 degres it is moving too slowly to be economical. At 1100 degrees C., the effects of overburning are very evident, showing itself both in the specific gravity of the lime as well as in a marked retardation in the time and completeness of the slaking of the lime thus burned.

The fact of the matter is, that for the economic production of lime of the highest type, the best temperature is one which does not exceed 1000 degrees C. to any extent, and the range of temperature should be not wider than from 950 to 1050 Popular opinion seems to be that different limestones require different temperatures, but the writer's experience would indicate that the temperature is approximately the same for the burning of chemically prepared carbonates of lime as for the amorphous and crystalline limestones. Dolomite limestone seems to require approximately the same temperature. While the same temperatures are required, it is probable that different amounts of heat are required for dolomites and for high calcium lime, as well as for limes made from stones of different physical character.

To burn lime with the greatest economy, it would first be desirable after a draw to bring the stone as rapidly as possible up to the highest safe temperature, and hold it there until the carbon dioxide was completely eliminated. With a kiln under such control it would probably be possible after a few experiments to draw more frequently; at any rate, the intervals between draws or the exact time to draw could be determined with accuracy, because it could readily be found out how long it was necessary that the high temperature be maintained in order to produce desired results. And the kiln might then be drawn at a stated interval after the stone had reached the desired temperature. The effect of an excessive temperature upon lime is to promote crystallization as well as a tendency towards the reabsorption of carbon dioxide. Lime in order to be in its best and most sensitive condition should be essentially an amorphous product, therefore the temperature used should be such as to bring it just below the temperature at which crystallization would begin. The object of approaching as near as possible to the safety limit for the quality of the product is to get the greatest capacity from the kiln by burning as rapidly as possible. The increased capacity, of course, means increase of production and reduction of cost.

Temperature measurements and accurate control would apply to all processes and all systems in burning alike, and in every case are desirable.

To the manufacturer of hydrated lime this should be very valuable, because the lime which is burned at just the right temperature will be more readily slaked, and the slaking will be more complete than with any other lime, and the resultant product will contain the largest possible amount of the active hydrate sought, and the percentage of tailings reduced to a minimum.

It is probable that this matter has not been given earlier consideration, because, *First:* It is possible to make a good grade of lime under present practices. *Second:* The more common methods of measuring temperature would be unsatisfactory in this case. *Third:* It is only recently that instruments have been perfected which are of such a nature that they could be used with success. *Fourth:* The lack of familiarity of the lime manufacturer as a rule with technical problems and technical appliances, and his general attitude of skepticism with reference to the use of any scientific methods, or any delicate instrument.

There are many methods of heat measurements which are entirely impracticable as far as lime is concerned. No instrument which must be introduced among the material or come in actual contact with it can be used. Pyrometric cones are clay and silica mixed with fluxing minerals, made to melt at a given temperature. These could not be so placed as to be observed, and even if they could, they would melt and spoil considerable lime by fusing with it. The platinum rhodium couple, encased in a porcelain tube, known as the Le Chatelier pyrometer, could not be used on account of the necessity of introducing this within the highly heated zone occupied by the lime, which frequently shifts and moves and would destroy the pyrometer.

The best means left is the use of an optical pyrometer. With this instrument, the measurement of the temperature is accomplished by observing the amount of radiation of either light or heat or total energy radiated. The optical pyrometer has been considered by those who know nothing about it as a very fine piece of mechanism, which, of necessity, is extremely delicate, and not fitted at all for general use in the industries, and one as only available for reliable results in the hands of an expert. Such is not the case, however, as a number of optical pyrometers have been designed with sufficient strength and simplicity to be available for use by a very ordinary workman, who has been instructed what observations to make upon the scale.

Temperature of bodies may be estimated from the radiant energy emitted by them, either in the form of visible light radiation, or of the infra-red waves that are studied by their thermal effects.

A number of pyrometers are based on the photometric measurements of the intensity of light emitted from incandescent bodies. Most of them are built to measure the intensity of red light radiation only, for two reasons: *First:* Because the color of the light from the incandescent source will undergo wide variations, as the temperature changes, and *Second,* because it is difficult to compare with a standard. So by passing the radiation from both sources through red glass, it is reduced to a comparison of two lights of the same color, and it is then a question only of intensity. What is more important to a lime manufacturer, however, is the fact that the intensity of radiations may be accurately measured and shown on a scale or on a registering sheet and by instruments which are not so delicate as to be readily broken in their use about ordinary industrial operations. The fact that ordinary diffused light, or even artificial light, lies between the incandescent body and the instrument does not materially interfere with their operations, but simplifies their use.

Optical pyrometers constitute a group of heat measuring devices operating at a distance or radiation pyrometers, and include all methods in which the pyrometer is separated from the body whose temperature is measured. We have in this class those which estimate strument based on the measurement of the energy of total radiation, and has come into practical industrial use. With this instrument the radiation of an incandescent body, such as lime within a kiln, which could be made visible through a small hole in the kiln wall, is focused upon a very minute and sensitive thermo couple, the temperature of which is raised by the radiations.

The rise of temperature develops an electro motive force in proportion to the intensity of the radiated energy. This electro-motive force is registered by a sensitive potential galvanometer placed in series with the couple. This is a direct reading instrument, since by means of a pointer over a scale on the galvanometer we may read the temperature. One of the difficulties of this instrument is in realizing a suitable material for a lens, which must be transparent for all radiations. For temperatures above 900 degrees C. fluorite answers. An industrial type of the pyrometer just described is made by using a large glass lens, instead of a small one, made of fluorite, and instead of the delicate galvanometer, one of the same type and sensibility as those used in thermo-electric work is substituted. The resulting instrument is robust and sufficiently sensitive for all practical uses, and has a range of temperature measurement from 800 degrees C. to 1600 degrees C. It is calibrated by direct comparison with a thermo couple, and the location of the needle corresponding to the various temperatures engraved upon the galvanometer scale; so that here an instrument is attained which can be used with a reasonable degree of accuracy and safety at the ordinary lime plant. This instrument for use should be calibrated if actual temperature of the lime is desired. For use on lime it should be calibrated or standardized against this material by heating lime, electrically or otherwise, so that readings may be made with a thermo couple and with the pyrometric telescope and the location of the various temperatures needed marked upon the scale. For the observation of temperatures of other incandescent bodies, the instrument should be calibrated against the material, unless the proper correction is known for the variation in the intensity of radiation for these bodies when at the same temperature.

Duration of Burning.—Both for economy in manufacture and quality of the product, the limestone should not remain in the highly heated zone any longer than is necessary to completely remove the carbon dioxide. This length of time will depend on three factors:

First: The size of the limestone blocks fed to the kiln. The smaller the blocks, the less will be the time necessary for the heat to reach their center, other things being equal

For instance, one hour or less at 950° C. was sufficient to decarbonize ground limestone. This would hardly be sufficient for lumps of three or four inches in diameter. There are other factors, however, which prevent too great a reduction of the size of the lumps to be burned, viz: ability to get sufficient draft through the kiln, and the demand of the trade for large lumps, or coarse lime.

It is obvious that for the manufacture of a uniform product throughout, it will be necessary to feed the kiln with stone of approximately a uniform size. In the opinion of the writer, stone considerably smaller than is the general practice could be used to advantage. The limits of size might be defined as follows: All lumps should pass through a hole six inches in diameter, and all should remain on a screen with holes three inches in diameter.

Second: The intensity and volume of the fire, and the amount of preheating the stone has had prior to reaching the hottest zone, as well as the kiln pressure. For instance, if a very small draw is made, the stone which drops down to the hottest zone is at nearly the desired temperature, and will need to be exposed to the high heat for but a short period. On the other hand, if a very large draw is made, much of the stone brought into the hot zone will be comparatively cool yet, and its surface will have to be exposed to a high heat for a much longer time, in order that the heat may penetrate to the core. This is apt to give either a thin skin of overburned lime over every lump, especially if the lumps are large, or else leave a core of unburnt lime in the center.

Third: The nature of the fire. By this is meant whether the fuel or method of firing is such that some of the gases will be carried in among the lime lumps, and there burned, heating the lumps on all sides, or whether the fire or center of combustion is entirely within the furnace. Also, whether the fuel or method of firing is such that moisture will be formed as a product of combustion in the highly heated zone. This latter consideration not only affects the duration of time needed, but also the temperature requisite for good results.

The Amount of Heat Required.—This can be determined with a fair degree of accuracy for the comparatively pure high-calcium limestones, but for the dolomites we can only theorize, since the largest single factor in the heat consumption has not been determined for dolomite; i. e., the heat required to break up the chemical union between the oxides and the carbon dioxide is unknown for dolomite. The heat of dissociation for calcium carbonate, as given by the different authors, varies somewhat. E. W. Thompson gives it at 425.2 calories. Others have named lower figures. We, however, accept that given by Ostwald as being the most recent and more accurate, which is 437.4 calories.

We have already shown that the best burning temperature is between 950° C. and 1050° C. when steam or water-vapor is not introduced. Herzfeld has shown that some limestones require as high a heat as 1040° C. The record of the very few measurements made in actual practice would indicate that the temperatures actually used are somewhat higher—1100° to 1150° C. The temperatures at which the gases leave the kiln vary widely at different plants, and to a less extent at the same plant at different periods of firing. The amount of heat saved from the cooling lime also varies. Very little of this heat is utilized by Ohio manufacturers.

For the sake then of getting comparative evidence, we will assume certain conditions to exist, in order to see what influence different conditions have on fuel consumption. The conditions selected will be as near as it is possible to get at those actually used in manufacture, as determined from the results of the few very meager and oftentimes indefinite observations made on plants in operation. The following data are taken as representing as near ideal conditions as we could hope to find in practice, as a basis from which to work.

First: A pure dry calcium carbonate limestone.

Second: An atmospheric temperature of 20° C.

Third: The gases leaving the top of the kiln at temperature just below 100° C., so as not to lose the latent heat of vaporization of water.

Fourth: A burning temperature of 1040° C.

Fifth: Amount of heat saved from the cooling lime equal to 10% of its total heat.

Sixth: Air excess of 10% over the theoretical amount required for perfect combustion.

Seventh: In the cement industry, it has been shown that 12.8% of fair the available heat in the fuel is lost by conduction and radiation; it is to assume that at least 10% would be used in this way in lime burning.

The heat consumption is made up as follows:

First: That required to bring the limestone to the proper temperature, which, since the carbon dioxide gives back nearly all its heat again, is the heat required to raise the amount of lime in the limestone to the desired temperature, plus that carried out by the carbon dioxide from the limestone.

Second: The heat consumed in the decomposition of the limestone. As an offset against the sum of the above, will be the heat saved from the cooling lime.

The Available Heat of the Fuel.—The available heat of the fuel will be the calorific value of that fuel, minus the heat carried out by the products of combustion and the excess of air used. Another minus factor in the available heat will be the allowance made for loss due to radiation and conduction.

We will take an Ohio coal, the calorific value and analysis of which is at hand, and get its available heat for this purpose.

Calorific value................................7293 calories

ANALYSIS.

Carbon	72.65
Hydrogen	5.06
Oxygen	8.95
Nitrogen	1.34
Sulphur	2.89
Ash	9.10

From this we get the following data, for each unit of fuel burned.

Carbon dioxide, produced from the carbon	2.663
Water, produced from the hydrogen	0.455
Sulphur dioxide, from the sulphur	0.0578
Nitrogen present and brought in,	7.596
Air required for complete combustion	9.87

From the above, the losses in burning this fuel, under the conditions named above (10% air excess, and gases leaving the stack at 100° C. or 80° C. higher than the temperature which the air and fuel had when entering), will be as follows:

		Calories.
Carbon dioxide	$2.663 \times .22 \times 80$	46.869
Water	$0.455 \times 1 \times 80$	36.400
Sulphur dioxide	$0.0578 \times .15 \times 80$	0.694
Nitrogen	$7.596 \times .24 \times 80$	145.843
10% air excess	$0.987 \times .237 \times 80$	18.714
Total		248.520

7293—248.5=7044.5 calories.
7044.5—10% (radiation loss)=6340 calories.

This amount is actually available to burn the lime, if we neglect the small loss due to heat carried out in the ashes, and the larger loss due to unburned fuel remaining in the ashes.

Heat Required to Produce the Lime.—Since the stone goes in at 20° C., and is raised to 1040° C., the temperature difference will be 1020° C. The lime produced will weigh fifty-six per cent. of the weight of the stone, and its specific heat is 0.22. Hence, we have:

	Calories.
Heating of the lime—$1020 \times .22 \times .56$	125.664
Heat carried out by the carbon dioxide—$.44 \times .22 \times 80$	7.744
Heat required for the decomposition	437.400
Total	570.808
Heat saved from cooling lime 10%	12.566
Total	558.242

With this fuel then, we could get $\frac{6340}{558} \times 0.56 = 6.36$ pounds of lime per pound of fuel.

Burning in an atmosphere of superheated steam, we would need, according to Herzfeld, a temperature of 790° C. Hence, 790—20=770, net temperature difference.

	Calories.
For heating the lime—770×.22×80	94.864
Heat carried out by the carbon dioxide—.44×.22×80	7.744
Heat for decomposition	437.400
Total	540.008
Saved from cooling lime	9.486
Total	530.522

Assuming that 0.5 pounds of water is introduced at the temperature of the air, we have reduced our fuel efficiency by 0.5×1×80=40 calories. This is the best way to express it, since if steam is used it will cost more to generate that steam under pressure than to evaporate the water in the kiln, and the heat units in the steam are only transferred from the boiler fire to the kiln, and at that with a loss due to transmission in the pipes including leakages, radiation, and energy consumed in friction. We now have as available heat from our fuel 6340—40=6300 calories. That is, this heat under these conditions will give $\frac{6300}{530.5}\times 0.56=6.65$ pounds of lime for one pound of coal.

Let us now consider the result of a different set of conditions, such as are often met with in practice today.

First:	Assume the kiln gases leave the stack at	320° C.
Second:	Outside air	20° C.
Third:	Air excess	100%
Fourth:	Same fuel as before, calorific value	7293 calories.

The losses will be made up as follows:

		Calories.
Carbon dioxide, from carbon	—2.663×.22×.300	175.8
Water and steam, from hydrogen	0.455.×1×80=36.40	
Sensible and latent heat	0.455×.48×220=48.05	
	.455 × 536=243.88	328.3
Sulphur dioxide, from sulphur	0578×.15×300	2.6
Nitrogen	7.596×.24×300	546.0
Air excess 100%	9.87×.237×300	701.7
Total		1754.4

7293—1754.4=5538.6 calories.
5538.6—10% (radiation)=4984.74 calories.

This is the number of calories available for lime burning, if we neglect the unburned fuel in the ash, and heat carried out with the ashes.

The lime requires the same heat as in the former case, where water was not used in the fire (558 calories for pound of limestone). Therefore, we have in this case $\frac{4984}{558}\times .56=5.00$ pounds of lime per pound of fuel.

Now, if per pound of fuel, we add 0.5 of a pound of water at atmospheric temperature, we will increase the losses through the kiln stack by:

		Calories.
Sensible heat of water	$0.5 \times 1 \times 80 =$	40.0
Sensible heat as steam	$0.5 \times .48 \times 220 =$	52.8
Latest heat as steam	$0.5 \times 536 =$	268.0
Total		360.8
7293—(1754.4+360.8)	=	5177.8
5177.8—10% (radiation)	=	available 4660.

Since under these conditions, the one pound limestone requires 530.5 calories, we have $\frac{4660.0}{530.5} \times .56 = 4.9$ pounds of lime for one pound of fuel.*

It is evident, therefore, that if good economy is to be obtained when using water or steam with the fire, the gases must leave the top of the kiln at a low temperature, below the boiling point of water, so as not to lose the heat that would be carried out as latent heat of vaporization of the water. The air excess is an important factor in both cases. While the presence of superheated steam does undoubtedly reduce to temperature necessary for burning, it is very probable that it does not reduce it in practice to the extent used in the calculations. Steam also undoubtedly accelerates the evolution of the carbon dioxide, since in every case observed, where steam was introduced, the kiln capacity was at once increased.

In using coal only, the air excess is apparently a more important factor in losses than is the temperature of the gases leaving the stack, and the loss due to the latter is by no means small, but is materially increased by the former.

The same method of calculation would hold for dolomite, and the efficiencies shown when burning under different conditions will show the same general relation to each other, since the only unknown factor is the amount of heat required for its decomposition, and this would be a constant for all of the different conditions just the same as the heat of dissociation of calcium carbonate or calcite remains a constant in all the calculations so far given. Until the heat of dissociation is accurately determined, no reliable figures can be given for the heat consumption in the burning of dolomite to lime. Many manufacturers, who have had experience with both, say it takes more fuel to burn dolomite than to burn calcite or high-calcium stone.

There is probably no industry in the United States today that could apply the knowledge of the chemist and technologist to so good an advantage as could the lime industry. The lime manufacturer seems to have been very slow in realizing that there was a chance to improve on his methods of manufacture. He seems to have been satisfied so long as he was getting as much lime for a pound of fuel as he thought his neighbors were getting.

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*Calories $\times \frac{9}{5}$ = B. T. U. Degrees Centigrade $\times \frac{9}{5} + 32$ = Degrees Fahrenheit.

From the calorific value and the analyses of coals, the fuel best adapted to any given conditions may be selected. In other words, fuel can be bought that will give the greatest results for each dollar spent. By analyzing the kiln gases, and measuring the kiln temperatures and temperatures of the escaping gases, the method of operation can be adjusted so as to get the best results under the circumstances, and determine what is needed to still further increase the efficiency of a plant. With a knowledge of the coal bill, and the output, it is easy to calculate what it would mean to a business, if the fuel bill remained stationary, while the output increased 20 to 30%. In the opinion of the writer, this is easily possible in many Ohio plants, as well as many without the state.

Draft.—The matter of draft is of some considerable importance. As indicated previously, all forms of induced draft, including the so-called natural draft, are to be preferred over forced drafts, since any decrease in the gaseous pressure within the kiln lowers the temperature at which complete expulsion of the carbon dioxide takes place, and any increase in the pressure raises the necessary temperature. In all cases, there must be admitted, or drawn in, sufficient air to bring about complete combustion, but the excess should be kept as low as possible. The loss due to this excess has been indicated previously. With natural draft, the height of the kiln and the size of the stone, and the thickness and tightness of the fuel bed will, in a large measure, take care of this, and openings to furnace and ash-pit need not be so carefully guarded as when mechanically induced draft is used. Nor need the bottom of the cooling chamber be so carefully closed, since the stack suction is so small that the velocity of the air entering any part is low, and, consequently, the volume of air brought in is small.

With mechanically induced draft, however, all air inlets should be carefully guarded, and only such air admitted as is needed, and the suction should be such as to produce a partial vacuum in the kiln, in order to get the best results. Of course, there are limits to this, since the air might be carried over or through the fuel at such a velocity that complete combustion would not be obtained, although sufficient oxygen had been admitted.

Lime manufacturers should use draft gauges on their kilns, and furnaces, and then when there were variations from what they had determined to be the best draft pressures, or what they have found to be normal conditions for their plant, they could immediately get after the cause and correct it.

Cooling.—When the limestone has been exposed in the kiln to temperatures of the proper intensity and duration, it must be promptly moved out of range of the intense heat or exposure to combustion gases, or "dead burning" will result in the one case and recarbonization in the other. The cooling of the freshly-burnt lime is therefore a part of the process which requires care and consideration.

Most limekilns have a more or less marked constriction at a point well below the middle height, at which point the fireplaces deliver their flames and hot gases. The lime passing this constricted zone reaches its highest temperature. Below, the kiln opens out in cross section considerably, forming an inverted truncated cone. Into this cavity the hot lime descends by gravitation as fast as room is made by removal of cool lime at the bottom.

The cooling is partly effected by fresh, pure air, which leaks in at the bottom. This air on entering takes up heat from the lime, reaching a higher and higher temperature as it rises, until opposite the inlets of the fire-holes it becomes as hot as the lime itself, or from 900° to 1200° C., according to the method of firing and general handling of the operation.

This preheated air furnishes some of the oxygen for the completion of the combustion of the flames and gases from the fireplaces. It naturally tends to produce a local and very intense temperature, while a diffused and more moderate temperature has been shown to be desirable.

It is apparent, therefore, that rapid and effective cooling by circulation of air in large volumes from below cannot be effected without disturbing the regularity and character of the burning process, as well as some recarbonization of the lime. Some air does make its way up through the lime, but it is not feasible to admit air in unrestricted amounts. Some cooling also takes place by radiation from the exterior of the shell or hopper or cone which forms the bottom of the kiln.

Neither or both of these methods operates with as much rapidity as is desirable, unless the cooling chamber be made very large, which necessitates extra height of the kiln and inconvenience in working around the bottom. Consequently, lime is generally only partially cooled in the kiln, and is often drawn while still red hot. When the cooling is completed in the open air, below the kiln, or on a floor near by, it means a loss of heat which should be returned to the kiln to do effective work there in saving fuel. It also heats up the atmosphere of the kiln-house and vicinity, and makes the work more severe for the operatives.

In some constructions, the hot air from cooling the descending lime is directed into the ash-pits of the fireboxes and is used in consuming the fuel. Naturally, it requires less fuel to heat up a column of air which enters the fireplace at 500° or 700° C., than if only cold air from outside were being used. The difficulty with this system lies in direct-

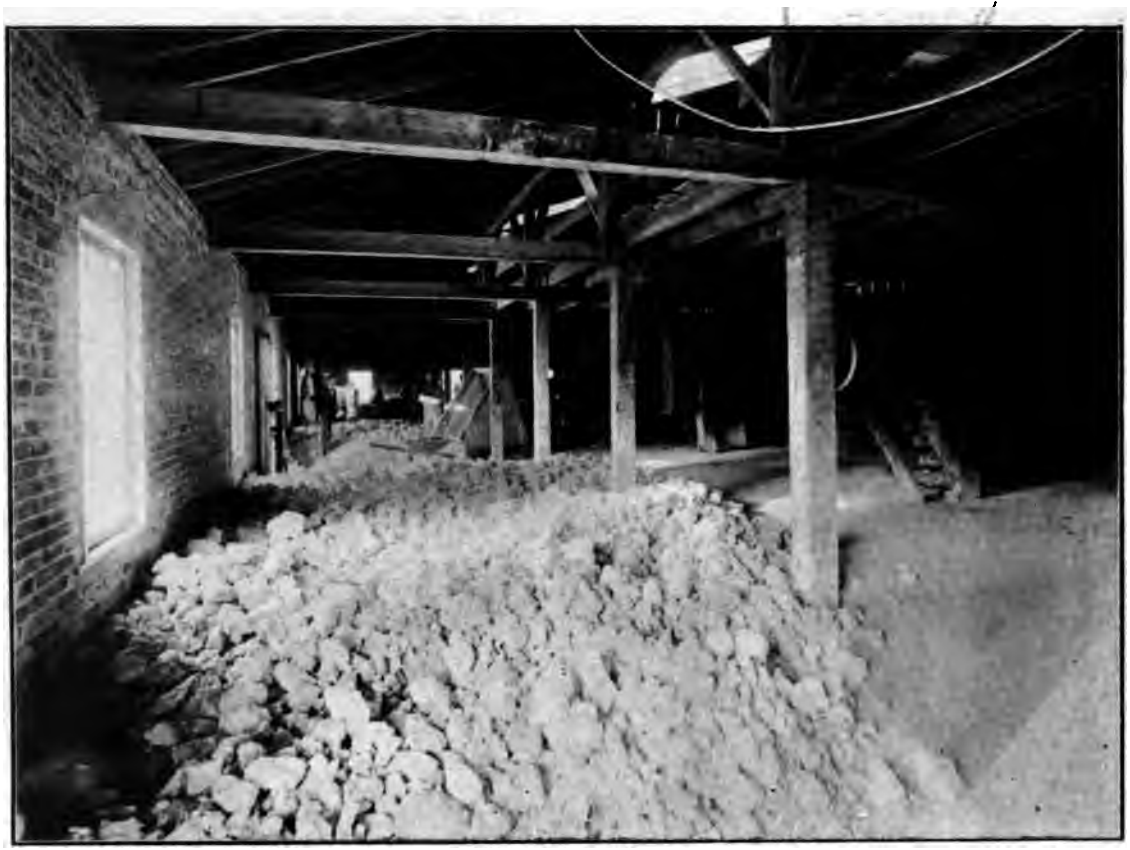


Figure 26.—Cooling floor of the Seneca White Lime Company, Fostoria, Ohio.

carbon dioxide of course becomes inert as a caustic agent. The effect reabsorbed of any appreciable quantity of air slaking in lime is to cause it to slake slowly and imperfectly, and in consequence of this, to work short and tend to be granular and lack plasticity. Yet, if air-slaked lime exposed for a long time is put over a very fine screen and only the finest particles used, a fairly good working putty can be made, and considerable sand carried by it, producing a good mortar. No one will buy it, however, if they know it. For use in agricultural purposes it should not be rejected or discriminated against, if it were purchasable on the basis of the amount of active oxides present, just as a pure, unaltered lime is supposed to be sold. The carbonates, in any case, are probably less undesirable than the imperfect hydrates. The carbonates, being in a fine state of division and inert, act as a good filler and make a dense mortar without danger of expansion in the future, while with the imperfect hydrates there is always danger that this hydration will be slowly completed with expansion and eventual rupture of the surface.

Drawing.—The attachment most used for releasing the lime at the bottom of the cooling chamber when it is desired to make a draw is a shearing device. This consists of two levers with iron plates on them, so hinged that when they are drawn together the cooler is closed, and when pulled apart there is sufficient opening for the lime to fall out by gravity. At some plants, the lime is allowed to fall into hand barrows; at other plants the kilns are built high enough so that cars can be backed under the cooling chambers to carry the draw to a desirable place to complete the cooling, or to the car for shipment.

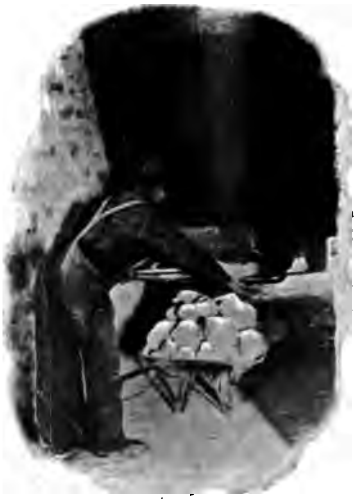


Figure 27—Drawing Lime.

The frequency of drawing varies at different plants. Four and six hours are the most common periods.

Continuous drawing is desirable from several points of view. If a continuous stream of stone could be kept passing the fire at such a rate as to just have the lime completely burned and no more, it would be an advantage to the quality of the product, since the constant movement would keep turning the stone, so that one side would not always be toward the hottest part of the fire. Screw conveyors have been used on the bottom of the cooling chamber. The objection made to this means of drawing was that the lime was broken up too much. Where the lime is used at once, or where hydrated lime is made, this would be an advantage rather than the opposite, since the finer the lime, if not air-slaked, the more readily and completely will it slake, and in many cases it is considered desirable to crush the lime before going to a hydrating machine. Also the amount of ground quicklime now going on the market renders the above objection less forcible than formerly, when there was a market for lump lime only.

Testing the Product.—The end desired in the manufacture of lime is the complete elimination of the carbon dioxide of the limestone or dolomite in such a way as to not impair the sensitiveness of any part of the product to the action of water. This means the production of a body which will, when agitated with the proper amount of water, rapidly and completely work up into a tough, very plastic, smooth, putty-like mass, with no gritty particles remaining. If the heat is insufficient, or of too short duration, the desired end will not be reached and cores or undecomposed carbonate will remain. If the heat is too great, dead-burning or overburning will ensue, and the lime will refuse to take up the water and form the putty, and the product will be gritty and "short." The term dead-burning is well used, since an overburned lime has a dead or dull appearance when compared to a properly burned specimen.

The skill of lime-burners becomes very great in time, and they can tell as soon as they look at a lump of lime with which they are familiar whether the burning was right or not.

Since the value of lime, for the most part, depends upon its ability to take up water and hydrate completely, and since the heat evolved in this process can be readily measured, it offers a very accurate way of determining the value of a lime, when its chemical composition is known. If it is not burned sufficiently, it will not develop the standard amount of heat, and if overburned it will develop the required amount of heat, but at a much slower rate.

For instance, working with 100 times as much water by weight as lime, the time required for a high-calcium or hot lime to develop all its heat of hydration, when burned at the following temperatures, was:

Temperature of burning °C.	Minutes to fully hydrate in 100 parts water.
900	4.5
950	4.5
1000	7.0
1050	9.0
1200	11.0

Lime of any given composition, burned under correct conditions, will always give out the same heat on being slaked. Rough comparisons on the same lime may be made from time to time, with the following apparatus: *First:* Provide a pail with a mark on it, *Second:* Fill it to the mark with water. *Third:* Take the temperature accurately, by an ordinary thermometer. *Fourth:* Dump in a standard amount of crushed or pulverized lime (always using the same quantity, of course. One pound is a convenient quantity). Stir the water and lime with a paddle, meanwhile carefully noting the increase in temperature, and the length of time required for the water to reach the maximum temperature. The quality of a lime can soon be accurately determined for all practical purposes, in this simple manner. Lime which has been air-slaked will behave just as if the lime had not been sufficiently burned.

Another good way of examining a lime is to measure its specific gravity. When prepared to do this, it can be done very rapidly. Kerosene oil is an excellent and cheap medium in which to weigh the lime, since lime is entirely insoluble in it. The arrangement used in the work recorded in this article was a small flask, of accurately known volume when filled to a certain mark. The lime was weighed out in powdered form, and introduced into the flask, which was then filled with oil from a burette or graduated tube. The difference between the volume of oil used, and the volume which the flask could contain, gives the volume of the lime used, and since this volume of lime was previously weighed, the specific gravity is obtained by dividing the weight in grams by the volume in cubic centimeters, since a cubic centimeter of water weighs one gram. If the volumes were in ounces or pints, and the weight in pounds or ounces, we would have to divide the weight of the lime by the weight, expressed in the same measure, of a volume of water equal to that of the lime.

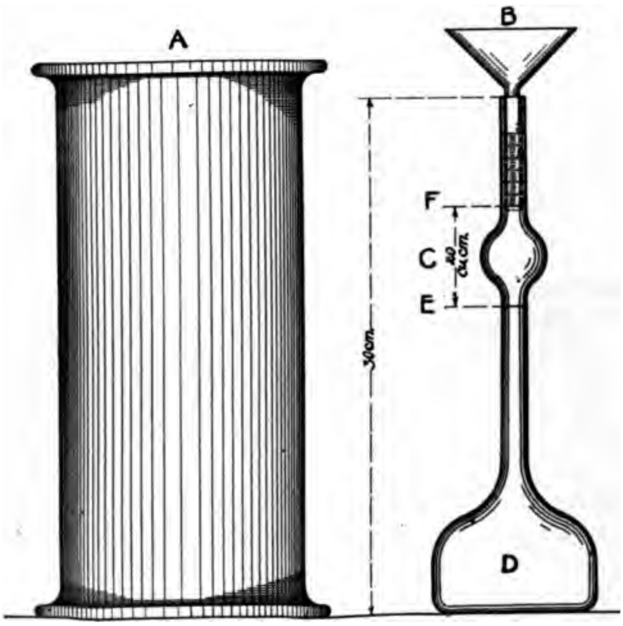


Figure 28.—Specific gravity apparatus according to Le Chatelier.

In the experiments made on the proper temperature for burning the specific gravity of the product was used for observing the quality of the lime, and the table given at that place shows that the specific gravity is a fairly good index.

If a lime gives a specific gravity of much less than 3.15 or much beyond 3.3, the assumption may be reasonably made that it is a poorly burned lime, or an air-slaked lime, or an impure lime. Two Ohio dolomite limes, sampled as soon as the kiln was drawn, gave a specific gravity of 3.15 and 3.16 respectively.

Because one lime gives up more heat on slaking than another, it does not follow that the hotter lime is the best, otherwise the limes made from dolomite would be thrown out at once. It is merely a means of showing how well any lime of a known composition has been burned. The specific gravity is essentially the same for all when properly burned. If the determinations were carried to a fine degree of accuracy, the dolomite limes would probably show a slightly lower specific gravity than does calcium oxide. A convenient form of specific gravity apparatus is that of Le Chatelier, shown in Figure 28.

Patented Processes and Appliances.—There have been granted in the United States no less than 190 patents on limekilns and kiln attachments. Of this number, only about 40 are worthy of study.

The patents on the general idea or principle involved in the use of cooling chambers and forced draft by means of fans have expired, and are now public property. Special devices for accomplishing the same thing are still patented, and it is probable that more will be granted.

The specifications of any patent may be obtained at a cost of five cents per copy, by ordering by number from the Commissioner of Patents, Washington, D. C., and enclosing the money for the patent specifications ordered.

The following list of expired patents contains the numbers of those which the writer considers most important in the history of the development of the industry:

217,415
134,292
220,337
220,478
1,476
152
120,278
41,691
330,603

A few unexpired patents which might be looked over with profit are:

509,439
443.865
358,437
503,059
593,246
513,945
399,496
566,106
407,406
530,125
443,779
399,495
521,295
459,693

Among the more important patents still in force are the following

718,075
414,350
670,047
667,599
436,426
506,029
546,935
712,251
453,774
677,418
708,240
692,257

Notwithstanding the fact that so many patents have been issued, comparatively few lime manufacturers in Ohio are paying a royalty on the use of kilns or kiln attachments. Comparatively few of the patents on limekilns have brought the inventor much of a reward from a financial standpoint.

SUBSEQUENT TREATMENT OF THE OXIDES.

Lump Lime.—When lime is to be used in the lump form, all that is done with it is to cool it by spreading it out on floors, after which, if it is to be shipped in bulk, it is wheeled into the cars. If it is to be barreled, it is put in and the barrels headed while the lime is still quite warm. It costs twelve to thirteen cents per hundred pounds to barrel lime, including the barrel and labor. Within the last few years, there has come into use a bag as a container for lump lime. This bag holds approximately one-half barrel of lump lime, and the cost of two sacks is essentially the same as the cost of a barrel, but the labor cost in filling and tying is slightly less than that for filling and heading the barrel. The introduction of this bag has been a good thing for lime manufacturers since it gave them a lever with which to control the dealers in cooperage stock, and the coopers themselves. If there is an apparent shortage of staves and cooperage goes up, the lime manufacturer simply orders a supply of these sacks and goes on. These sacks consist of a paper sack, which has received a coat of water-proofing material. The paper sack is encased in a coarse burlap bag, but is made larger than the burlap bag, so the latter must carry the strain.

Ground Lime.—When the lime is to go on the market ground, it is cooled, run through a crusher, and from this to a Sturtevant or Steadman mill. The prevailing mill in use in Ohio plants at present is the Steadman, but most of those recently installed have been of Sturtevant make. The principal market for ground lime is the flint glass and plate glass industries. However, there is quite a large amount being used in the building trades, and the demand is constantly growing in this direction, since there is very little difference in price and when barreled it keeps better than lump. Also, owing to its fine condition, it slakes more quickly and completely when needed for use. Lime for the glass trade is usually ground to 80 mesh, and the same product is shipped to the building trade. As was shown in chapter V, quite a large amount of lime is crushed for agricultural uses. For this purpose it is left very much coarser than for the glass trade, frequently being shipped just as it comes from the crusher. This is usually shipped in bulk.

Prepared or Hydrated Lime.—Hydrated lime is fast coming into use. If manufacturers make a business of preparing lime, they learn how to handle it to bring about the best results. The strongest factor in favor

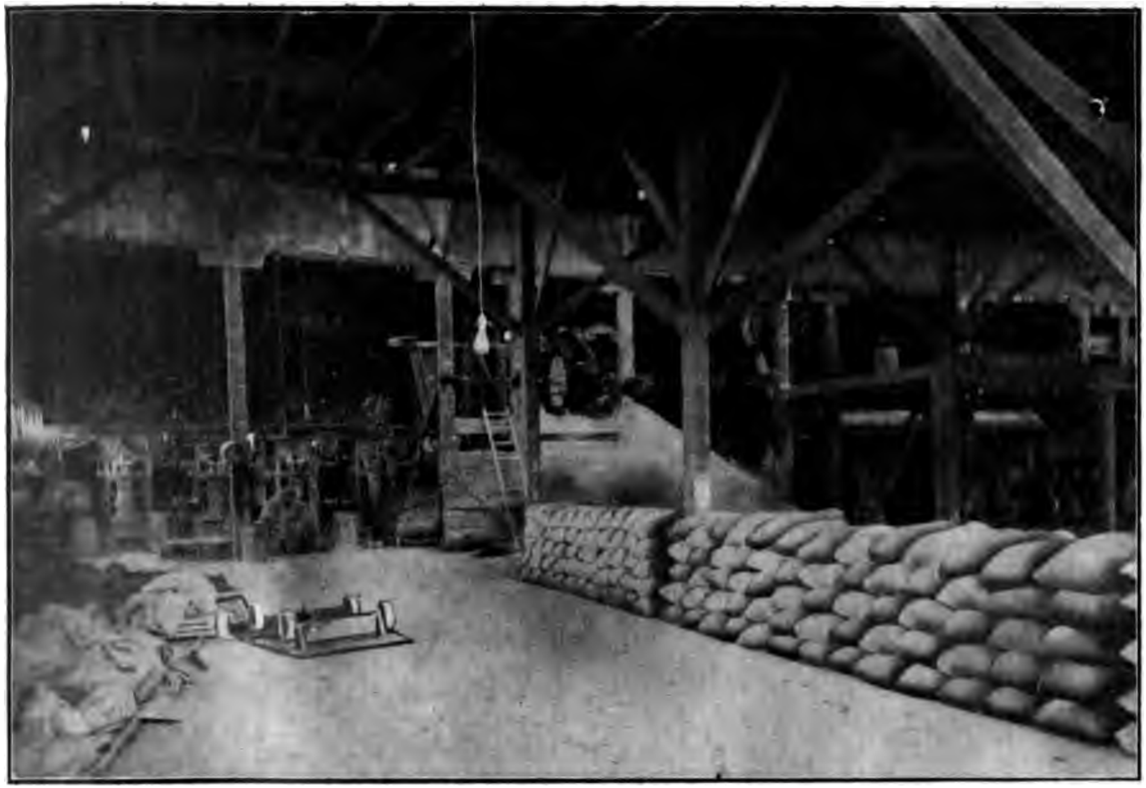


Figure 29.—Hydrated lime on the floor, ready for shipment at the plant of the Standard Lime Co., Gibsonburg.

of hydrated lime is that it can be stored in paper bags, and does not materially deteriorate with age. This gives it a tremendous advantage with the small consumer, as soon as he realizes that it answers all the ordinary purposes of quicklime, without the inconvenience of slaking it.

Another advantage lies in the fact that it does not require to stand for several days before using. If mortar or plaster is wanted in a hurry, it can be had.

Prepared lime is always put on the market in the form of a dry powder. It is claimed by the manufacturers that it will carry more sand than an equal weight of quicklime. This can hardly be the case, since an equal weight of fresh burned quicklime, properly slaked, would have more of the active agent present.

However, since in practice quicklime is seldom used before it is 7 to 10 days or more old, this claim of the prepared or hydrated lime manufacturer may be largely true, under average trade conditions. Few people realize how much air-slaked lime they buy, since it can not be detected by the ordinary observer until it is very much below its proper or original strength. This air-slaked lime is largely inert, and acts as a good filler, since it is very fine of grain, but such part as is not inert is apt to make trouble later, if present in any quantity, especially if used on walls or exposed surfaces. It is lacking in normal water content, and may in the future gradually acquire that water and expand. The part of the air-slaking due to reabsorption of carbon dioxide will cause no trouble. At any rate, the presence of air-slaked lime reduces the value or strength of the lime very rapidly, and makes it work badly under the trowel. For a unit of lime purchased, you get less of the active agent desired. The prepared or hydrated limes are slaked at once, before any appreciable amount of air-slaking sets in, if the lime has been properly handled in the cooling, and, hence, are more uniformly efficient, nor are they in danger of spoiling or deteriorating by long standing.

Whatever the relative value of quicklime vs. hydrated lime may be, the mixing of the lime and sand is certainly greatly facilitated by first mixing the ingredients in the dry state, and then incorporating the water, since it is much easier to mix two dry bodies than to work a small amount of a very tough plastic body among a large amount of practically dry particles in such a way that distribution shall be uniform.

The hydrated limes may well enter all the markets supplied with quicklime, except for certain chemical operations, in which the water of hydration would be objectionable, and only the oxide form desirable. Further, hydrated lime is much used in the manufacture of hard wall plasters or dry mortars, which was not the case when only lump or ground lime was to be had. This use will increase. It has been shipped abroad by water tansportation. When properly hydrated, this is entirely safe, as there will be no danger of heating, even if it does get wet.

You would have considerable difficulty to get a vessel to carry quick or unslaked lime on an ocean voyage, and many companies are afraid of hydrated lime.as yet, but in time they will learn the difference and carry it as willingly as any other commodity. The hydrate prepared from lime containing little or no iron can in many cases take the place of a much more expensive prepared chalk, whiting, or calcium carbonate of commerce. For instance, in the ceramic industry, where whiting or prepared chalk is used as a flux in glaze and body, hydrated lime of proper composition might be used at much less cost and produce equally pure colors of body and glaze. The hydrated lime manufacturers should investigate this field, and show the potter what he can do for himself. It must be borne in mind, however, that the weights used in a fluxing mixture will be different when using the hydrate, than when the carbonate is supplying the active agent. Thus 72 parts of hydroxide would be equivalent to 100 parts of carbonate.

Many patents have been granted on so-called processes for the manufacture of hydrated limes, and upon machines, and details of machines for carrying out the hydration, yet the writer does not look on the industry as covered in the sense that it prevents the manufacture of prepared lime without working under some patent. As a matter of fact, it is generally considered now that these patents are either limited in their scope, or of no strength at all, and that the prepared lime industry can be undertaken along numerous lines, without fear of patent litigation. To do this will, of course, require a good knowledge of the general subject, and a selection of methods and machinery to avoid conflicting with such of the present patents as have not yet been definitely rejected by the courts. Recent court decisions also indicate that patents on processes for slaking or hydrating lime can have but little value. Such, however, need not be the case as to machinery, or details of machinery, or special devices for hydrating lime. So far as the writer is able to learn, no Ohio plants are paying a royalty at the present time for their hydrating equipment, and probably very few, if any, in the United States are doing so. If any are doing so now, they probably will not continue to do so for any length of time. There has been a great change in this respect in the last few years.

Patents on Hydrating Processes or Apparatus.—The citation of a few of the more important patents allowed, with a brief discussion of such as warrant it, will be of interest and benefit, and at the same time cover what has been done by the investigators in this field.

The two following patents, both of which have expired, cannot be classed as processes for making prepared lime, but come under the general head of subsequent treatment of oxides, since they were intended to reclaim spent lime by making it into blocks, which were then to be recalcined. *Patent No. 217,317* subjected spent lime to the direct action of the products of combustion from any furnace.

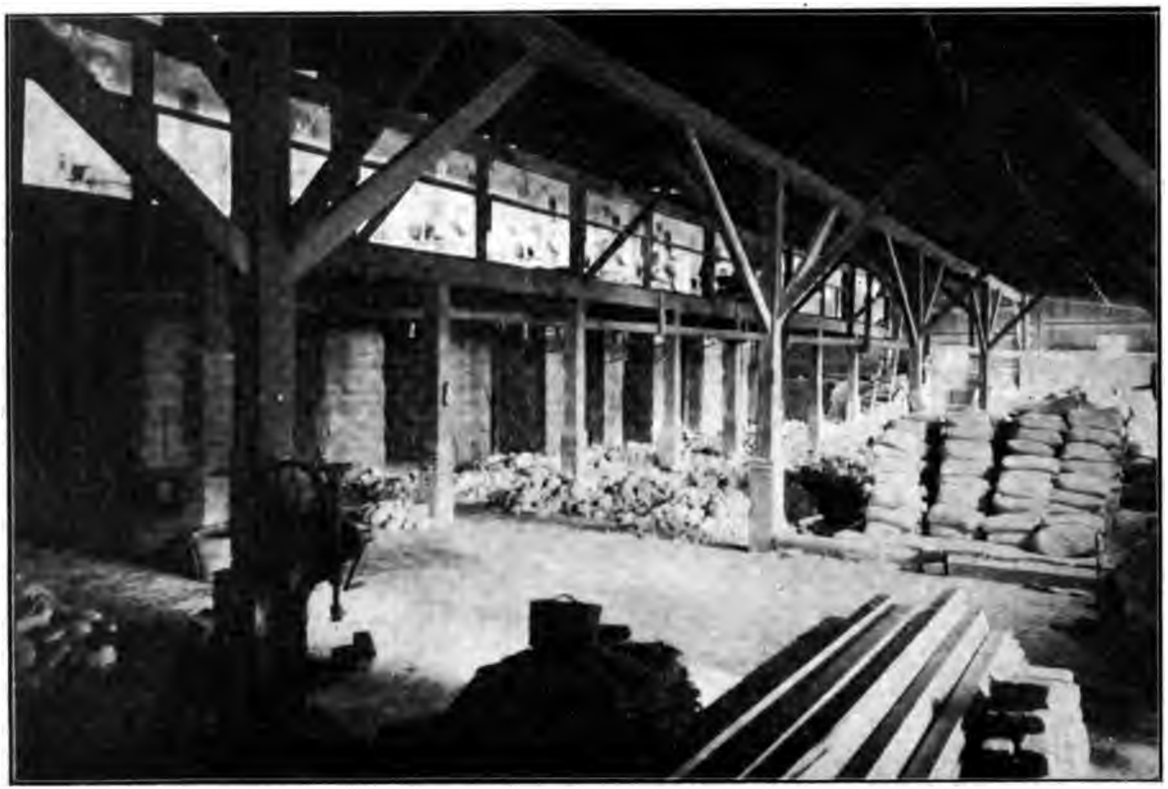


Figure 30.—Cooling floor on one side of kilns, at plant of Standard Lime Co., Gibsonberg.

No. 155,043 provided for the compression of ground quicklime into a package by hydraulic pressure, for the purpose of preserving its activity.

Patent No. 683,188, September 24. 1901. Granted to F. N. Spear, Los Angeles, California. Claim (1) of this patent practically covers everything granted; it is quoted below:

"The process for treating lime which consists in first slaking quicklime, and then when in a finely-divided condition, bringing the slaked lime into contact with carbonic acid gas."

This patent can have but little, if any, value, since it provides for putting back into the lime just what was removed by burning it. If calcium carbonate is desired, it might better be furnished by ground limestone.

Patent No. 622,388, April 4, 1889. Granted to H. H. Pierce, of Toledo, Ohio. This patent provides for the adding of ground calcium carbonate to slaked lime.

This is nothing more nor less than an open adulteration of hydrated lime, since the calcium carbonate is inert. We might just as well add so much very fine ground clean sand.

Patent No. 309,328, December, 1884. Granted to W. I. Adams. It has recently expired. This patent covered the slaking of pulverized lime by water, while being agitated in an enclosed vessel. If this patent had been brought into court, some of the more recent patents would have had difficulty in proving originality.

Patent No. 137,323. James L. Rowland, of Milwaukee, Wisconsin. This patent has recently expired. Claim 1 provided: "As a means of slaking a lime, hydraulic or common or air lime, and producing a hydrate, the application to the lime of water in very finely-divided particles, as steam or vapors, substantially as set forth." This was a very broad claim, and practically covered the use of water-spray or steam in any manner, for the purpose of slaking or hydrating lime. The following patent makes use of this principle, but does not call it hydration or slaking.

Patent No. 682,837, granted to Colby M. Avery, assignor to the Chisholm, Boyd & White Company, Chicago, Illinois. The claims are as follows:

"(1). The process of pulverizing lime consisting of the simultaneous agitation and sifting of said lime in the presence of steam.

"(2). The process of pulverizing and separating lime from foreign matter, consisting in simultaneously subjecting said lime to the action of steam in a confined space, and agitating and sifting said lime."

Patent No. 696,396 was granted to the same person and assigned to the same company, as the preceding patent, and provides a machine to carry out the above specified process.

Patent No. 663,459, granted to Wilhelm Olschewsky, of Berlin, Germany, covers a device for slaking lime consisting of a tight box, attached beneath a truck for carrying sand brick, and a means of introducing steam. The cover to the box is removable, and forms a table for the brick when on the .box

Patent No. 714,807, granted to Lynn T. Leet, of Montreal, Canada. Claim 1 provides:

"The combination of a cylinder capable of sustaining great pressure, a container for slaking lime, and means for preventing water of condensation from coming in contact with the lime in the container."

The above patent would seem to have no value, except in connection with, or by permission of, patent No. 702,611.

None of the preceding list have received commercial attention in Ohio. All of the following, except No. 721,871, have been used in Ohio. The first three, the claims of which follow, are said to be the property of the National New Process Lime Company, of New York.

Patent No. 543,452. The H. H. Pierce Company, of Toledo, Ohio. Specification forming part of Letters Patent No. 543,452, dated July 23, 1895. Application filed June 6, 1894. Serial No. 513,654. This patent covers a process of treating lime:

1. The herein described process of treating lime, which consists in, *first:* slaking quicklime to putty; *second:* roasting said putty, and, *third:* grinding the hard mass thus obtained, substantially as and for the purpose specified.

2. As an article of manufacture, lime which as quicklime has been slaked to a putty, then roasted and then ground, and which will not slake,,heat nor swell, substantially as and for the purpose specified.

Patent No. 599,792, granted to same party, makes the following claims:

"(1). The herein described process of treating lime which consists in, *first*, slaking quicklime to a putty; *second*, roasting the hydrate of lime thus formed in the presence of carbonic acid gas, and, *third*, grinding to a powder the product thus obtained, substantially as and for the purpose specified.

"(2). As an article of manufacture, lime which as quicklime has been slaked to a putty, then roasted in the presence of carbonic acid gas, and then pulverized, substantially as and for the purpose specified."

In the opinion of the writer, patent No. 599,792 is no improvement over No. 543,452, granted to the same party. In fact, the introduction of carbonic acid, and the consequent formation of calcium carbonate, acts simply as a dilutant or adulterant, which adds nothing to the quality and detracts from the strength of the product.

Patent No. 680,246. James H. Harrier of North Industry, Ohio. Specification forming part of Letters Patent No. 680,246, dated August 13, 1901. Application filed September 14, 1900. Serial No. 30,053. Two claims follow:

"(1). The herein-described improvement in the art of slaking quicklime, consisting in exposing it to moisture, and then excluding the air by a covering of pulverized slaked lime, substantiallly as specified.

"(2). The herein-described improvement in the art of slaking quicklime, consisting of exposing it to water on an inclined surface, and then excluding the air by a covering of pulverized slaked lime, substantially as specified."

Patent No. 543,452 will, if the heat is applied externally and not by direct contact with combustion gases, give the best possible results with any lime. The process, however, is too expensive of operation, except for the production of lime hydrate of special quality for specific purposes, which make unusual demands on this product.

Patent No. 671,621. Henry P. Dodge, of Toledo, Oh'o. Specification forming part of Letters Patent No. 671,621, dated April 9, 1901. Application filed February 15, 1900. Serial No. 5,372. The claims are as follows:

"(1). The herein-described method of treating lime, which consists in reducing fresh burned lime to a fine granular or pulverulent condition; agitating the mass, and, while in a state of agitation, exposing its particles to water in quantity sufficient to effect hydration; permitting the mass to cool, and subsequently sifting or screening the same.

"(2). The herein-described method of treating lime, which consists in subjecting, in the open air, fresh burned lime in the form of fine particles of powder, to agitation in the presence of water in quantity sufficient to effect its conversion into a hydrate, but not materially in excess of such quantity; and permitting the mass after such hydration to cool and assume a dry pulverulent form.

"(3). The process of treating lime, which consists in subjecting the same, while in a granular or pulverulent condition, to vigorous agitation in the presence of water sufficient to effect complete hydration, but not appreciably in excess thereof; permitting the mass to cool; reducing the same to pulverulent form; and screening or sifting the powdered mass to remove any particles of undue size."

A suit brought by the owner of this patent, for infringement, was recently lost on the ground that the patent was void.

Patent No. 678,500. August H. Lauman, of Allegheny, Pennsylvania. July 16, 1901. The claim is as follows:

"The herein-described method or process of treating lime, which consists in adding to burnt lime just sufficient water to convert the same into a dry hydrate, the mixture being constantly agitated and thoroughly commingled and air excluded and pressure maintained during the conversion of the burnt lime into a dry hydrate of lime."

A suit for infringement on this patent was lost, on the ground that it was not a patentable invention and therefore void.

The machine used for carrying out this process is continuous in its operation, having an automatic feed and discharge. The machine consists of a cylinder about three feet in diameter by about thirty feet in length, with means for agitating and moving the lime from one end to the other, in contact first with water and steam in the beginning of the operation, and steam only at the finishing end.

Patent No. 721,871, granted in 1903 to Byron E. Eldred, of Brooklyn, Massachusetts. Claims 1 and 2, which practically cover everything of value in this patent, are quoted.

"(1). The herein-described improvement in the art of slaking lime, consisting in treating moist slaked lime with sufficient dry quicklime to form a dry product, substantially as described.

"(2). The herein-described method of treating lime which consists in slaking lime with an excess of water over that required for chemical combination, and subsequently mixing with it sufficient quicklime to produce dry hydrate of lime, substantially as specified."

No new principle is involved in this patent. Any workman in slaking lime makes up a mixture of water and lime, mixing it to a putty, and then brings it to the desired consistency by the addition of water or quicklime, until he attains the consistency sought. The only difference between the two is in the end sought or consistency desired.

This patent will, without doubt, make a hydrate of excellent quality, at a very low cost from quick-slaking, hot, or high-calcium limes. For the slow-slaking dolomite or magnesian limes, it is probable that some of the other methods will be more desirable.

No matter whether a dry hydrate or a lime putty is desired, whenever the quantity used will justify it, mechanical agitation should be used while slaking, since the mixing can be more vigorous and thorough, and in consequence the distribution of the water more complete, and the resultant product more uniform and even in composition, than with hand labor.

Hydrating Equipment.—This consists of crushers, hydrators, conveyors, grinding and separating apparatus, bins, and sack packers. In most cases, the crusher is used as a preliminary step, before going to the hydrator,and in some cases the reduction is carried still farther by grinding before hydration; in some instances, however, the lump lime goes direct to the hydrator. Such is the case at the plant of the Scioto Lime and Stone Company, of Delaware. Nor does this company grind the product after hydration, as is usually done elsewhere, yet 90% of the hydrate passes a 200 mesh screen.

The crushers most used are small gyratory crushers or grinders, which reduces the lump lime in one operation to about 0.5 inch diameter and smaller. The same type is used as when ground or agricultural lime is prepared. When reduction is carried beyond the crusher, Sturtevant mills, Steadman mills, and impact pulverizers such the Jeffrey mill are in use.

Many kinds of mixing and agitating machines have received the attention of the hydrated lime manufacturer, as a means of procuring the best hydration of the lime. The wet mortar manufacturers were the first to use mechanical slakers in the state. They used pug mills, and almost every kind of mixing and stirring device. They have for the most part settled down to using shallow circular pans, with overhead arms, revolving in a horizontal plane, and carry-pins or projections, extending down into the pan for stirring. Some have a secondary mixing arrangement by placing on the end of these arms a device with four projections into the pan. This device is connected with the driving gear, and rotates at the same time the arms are swinging around.

An arrangement of this kind was patented and is in use at the Ferris Mortar Works, Columbus, Ohio. The New Process Lime Company, when operating at Genoa, used a fertilizer mixer, built somewhat on the order of the above machine, for preparing their putty. With this machine, the pan rotated beneath the arms, which were permanent, and only the secondary stirrers were caused to rotate. For the production of putty, both these machines proved very efficient. So far as the writer knows, the "wet pan" and "chaser," so much used in the clay industries for the incorporation of water and improvement in plasticity of clays, has not been tried. In the opinion of the writer, they would hardly prove desirable, since, where used in the sand-brick industry as a mixer and grinder, the mullers have tended to gather up the lime and carry it around with them, rather than make a satisfactory incorporation of it into the sand, unless the lime had been very evenly distributed through the sand in a dry state prior to its introduction into the wet pan.

While the grinding effect of the wet pan would probably be desirable in the early stages of hydration, this same compacting force, especially for dry hydrate, would be a disadvantage later, by compressing masses of the semi-plastic lime into cakes, which would dry out, and later have to be ground up. Every effort is made to keep the hydrate as fluffy and loose a form as possible. To produce dry hydrate starting with ground lime, open troughs with agitating and spraying arrangements have been used, but are practically abandoned now for enclosed circular mixers, somewhat on the type of the blunger used by clay manufacturers, but not so large.

The Clyde hydrator (see figure 31), which is the one in largest use today in this state, will be described in more detail. Two of these hydrators are in use at the plant of the Woodville White Lime Co., at Woodville, one at the plant of the Kelley Island Lime and Transportation Co., at Marblehead, and one at the Urschel Lime Co.'s plant, at Sugar Ridge. The rated capacity of these machines is forty tons per day, each. All of the machines in use are not, however, working to their full capacity. The Clyde hydrator consists of a revolving pan sixteen to twenty inches high and eight to ten and one-half feet in diameter, which passes under a series of plows, so arranged on an eliptical support that in one rotation of the pan every·portion of its surface shall be touched by a plow shear. The pan is driven by a 6x24-inch pulley running 175 R. P. M. The weight of the hydrator, complete, is 4,500 to 6,800 pounds, depending on the size. The accompanying illustrations give a better idea than can be given by description.

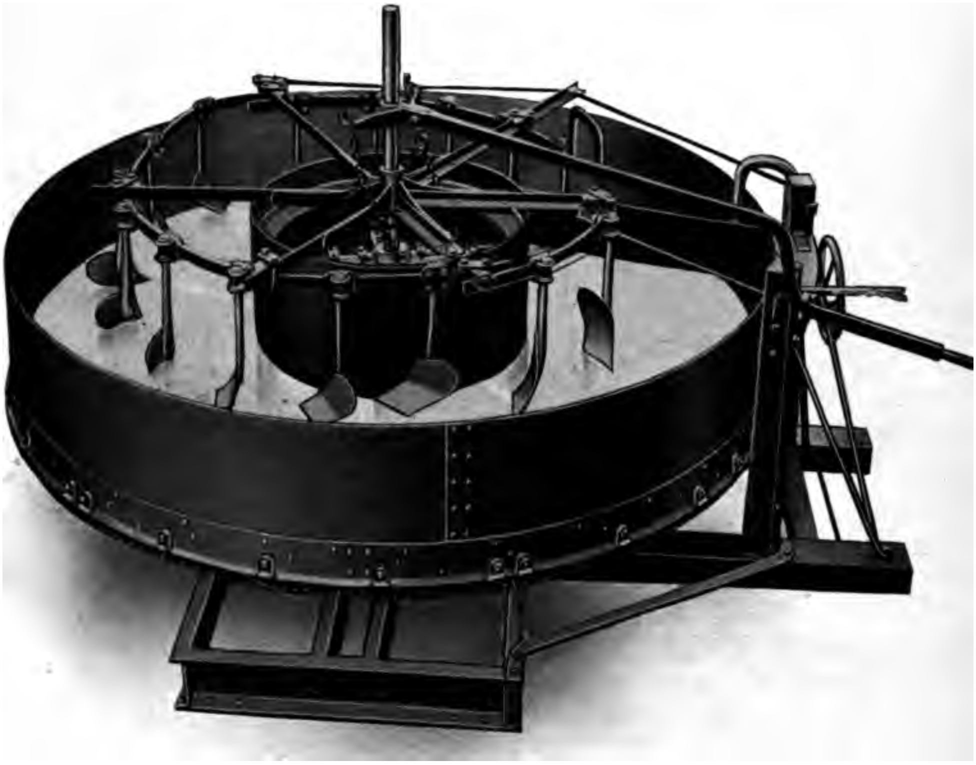


Figure 31.—Clyde Hydrator, general view.

The operation is as follows: The lime after being crushed is fed from a bin to a scale hopper, as shown in cut. When this is dumped a weighed amount of lime is dropped into the hydrator, which is in motion, and the scraper, shown in the right of the pan, levels up the lime in the pan. The water is next applied in definite quantity as measured in the tank, and by means of the sprinkler, all as shown in the side view. When all the water has been taken up, or passed off as vapor, and the lime hydrate is sufficiently cooled, it is dumped through the center by raising a circular rim, by the lever shown in both cuts, which at the same time lowers the leveling scraper which pushes all the hydrate to the central dump hole. When the hydrate is all out, the lever is released and the hydrator is ready for another charge. The pan rotates continuously. A hood and air shaft, as shown, is provided to carry off steam and dust. This hydrator seems to be producing a hydrate which answers ordinary market requirements. The manufacturers of the machine, The Clyde Iron Works, of Duluth, say the cost of hydrating allowing six per cent. for interest on investment, and six per cent. for depreciation, is twenty-five to fifty cents per ton of hydrate, depending on the size of the plant, and local conditions. The first cost of installation is low on this hydrator.

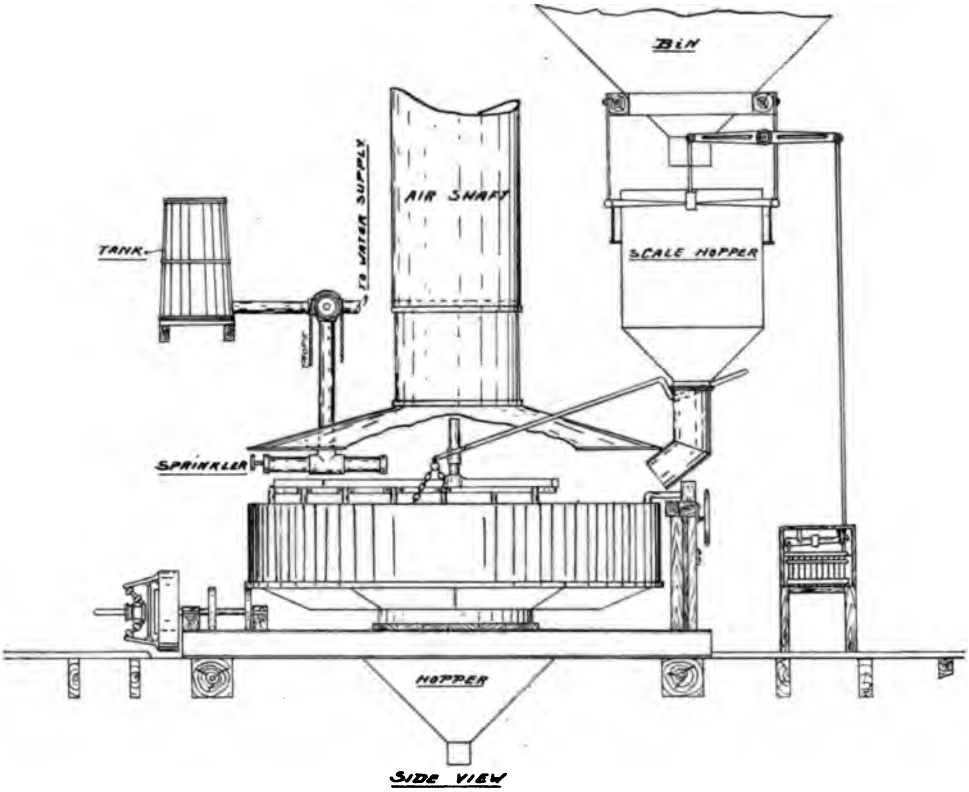


Figure 32.—Clyde hydrating plant.

The general arrangement of a plant equipped with these hydrators is shown in the plans of the Woodville White Lime Company, given on pages 355-359.

The hydrators thus far mentioned have all been intermittent in operation; the next is semi-intermittent, that is, it is periodic as to feed of lime and water, and continuous as to discharge.

The American Hydrating Company's hydrator, sometimes called the "Reaney hydrator," consists of an inclined cylinder, mounted on rollers similar to the mounting of a cement rotary kiln, as shown in the accompanying illustration.

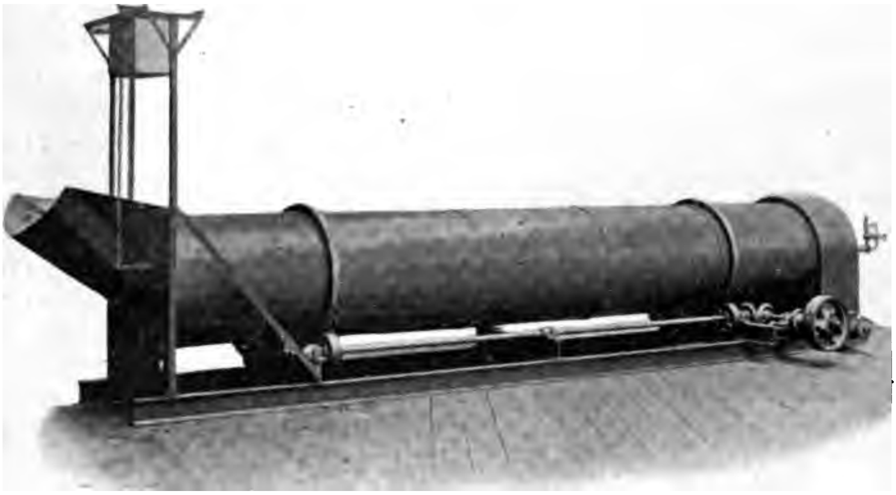


Figure 33.—Reaney Hydrator, made by the American Hydrating Company.

At the entry end there is a chute, within which there is a hinged door, which is connected with a flush tank located above. The tank to hold just the quantity of water desired is adjusted and made to discharge this quantity of water on each charge of lime of given weight, by a connection with the swinging door in the chute. There is a spray pipe within the machine, connected with the water tank, so that as soon as the lime has entered the hydrator, it is sprayed, and thoroughly mixed in the first section of the revolving cylinder. There are a series of rings encircling the machine within, that act as continuous retarders to the progress of the lime, and at these points some separation takes place, the lighter hydrated particles rising and passing over into the next compartment, where the process is repeated, the heavy unslaked matter remaining until steam and water has done its work. Connected to one of these rings is a tapered screen, over which all the material has to pass in order to gain exit. This screen may be encicled by a second screen of any desired mesh. The fine hydrated particles pass through the screen or screens on to the cylinder, and move slowly to the exit.

At the discharge end, there is a stationary hood containing a partition, beyond which the screens discharge as waste all particles failing to hydrate or pulverize. The finished hydrate falls from the end of the cylinder into a conveyor on the inside of this partition.

There is a perforated steam pipe entering the machine at the discharge end, which extends through its axis, supplying steam to the interior, thus preventing the entry of air.

There are also flights or baffle plates within the cylinder, which carry the material up and drop it through the atmosphere of steam, as the cylinder revolves. It is customary to feed this machine in weighed lots by wheelbarrow, a barrel of lump lime to a load No crusher is used. The first or water section is six feet in diameter and six feet long. The main cylinder is seven feet in diameter and twenty-four feet long. Capacity about six tons per hour. This is a patented machine, but is sold outright without royalties. The plans of the plant of the Scioto Lime and Stone Company, of Delaware, pages 351 and 354, which has a hydrator of the type just described, as well as another of smaller design, such as is intended for sand brick plants, shows the general arrangement of a hydrating plant of this type. With elevators and conveyors properly installed there need be no dust from this equipment.

The next type is one wholly continuous in operation, and is exemplified by the machinery in use at the plant of the Standard Lime Company, Gibsonburg, the plans of which are given on pages 360 and 365. This hydrator consists of a long, enclosed cylinder, in which the lime is agitated in the start with water and steam, and at the finish steam only. Crushed lime is automatically fed at a definite rate per minute in a continuous stream. At the same time, water and steam are entering in proper and definite amounts to accomplish the desired end. The discharge of hydrate is also under control, and is carried off at a rate proportioned to the lime entering, and delivers to the elevators and conveyors for cooling on its way to the bins entirely under cover, so there is no dust or loss of fine particles of hydrated lime. Continuous operation is always desirable in any industrial process. Hydrating in an enclosure is also desirable, since hydration is more complete in the presence of steam, especially if the steam is under pressure. The enclosed vessel also prevents dust in the plant, which is also desirable. Two of these hydrators are in use at this plant each with a capacity of four to four and one-half tons per hour. When slaking was started at this plant, an inclosed intermittent slaker was used, and led to the development of the machine just described. The old machine as shown in the illustration was a tight drum with two openings for putting in water and lime. These openings were then closed, and the drum rotated until hydration was finished. Then it was stopped, opened and the product dumped out and sent to grinder and separator. This machine did good work, but was too cumbersome in operation, and took too much labor.

Elevating and Carrying Machinery.—For this purpose, chain bucket elevators and screw conveyors are used.

Separating Machinery.—For this purpose, revolving bolters, screening devices, and air separators are used. With screens it is difficult to get close separation and capacity. Secondly, it is more difficult to keep dust out of the plant. Bolters are expensive in repairs, frequently costing as much as two cents per ton of hydrate. The air separator, nothwithstanding that it is expensive of power, is probably the most satisfactory machine for this phase of the operation.

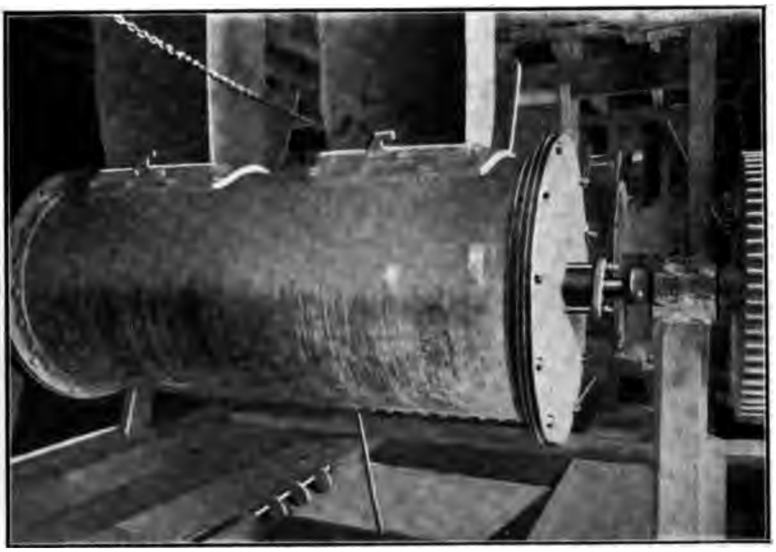


Figure 34.—Old form of hydrator, used by the Standard Lime Company.

Grinding.—For grinding, no new or special machines have been introduced. Those mentioned previously for grinding lime are all used for grinding hydrate or tailings, as the case may be. There should seldom be as much as five per cent. tailings, and, whenever possible, they are disposed of unground, and very little, if any, hydrate is ground; so the grinding machinery is a minor factor.

Storage.—The bins are and should be made of metal, unless the lime hydrate is thoroughly cool and dry before going to the bin. If moisture is still present, it remains quite hot for some time.

Packing.—For sacking, ordinary cement or flour packers are in use for the most part. Late in 1905 the Woodville White Lime Company put in a packer which has been used to some extent in other industries and proven very satisfactory for materials not requiring absolute accuracy of weight in a sack. This uses a sack already closed, as it were, since there is only a small opening in the corners, which closes itself when the sack is full. There is more or less dust always consequent to filling the sack and tying it in the ordinary way. With this packer, there is practically no dust driven out into the plant. Since it is the only one of its kind being used on ground and hydrated lime in the United States, and since Manager Urschel of this plant, up to the present writing, reports it as entirely satisfactory, and claims it introduces a large saving in labor, a brief description of it is given. With this machine eight bags can be filled at once. The machine has a rated capacity of six tons per hour on hydrated lime put into forty pound packages. There will, of course, be some variation, say a few pounds between different sacks, but Mr. Urschel has weighed up many tons, and says the total weight of the fifty sacks is always within a few pounds of a ton. The machine consists of a vibrating table, No. 1 in the illustra-

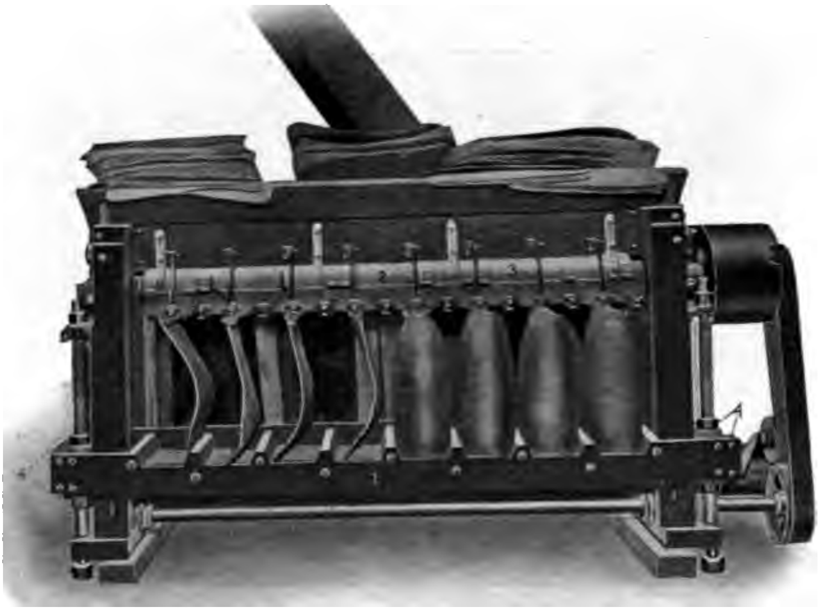


Figure 35.—Bates' Bag packing machine.

tion, which is set at such a height that the bag when placed on the filling tube through the self-closing corner, will have just a little slack, so settling and complete filling can be accomplished. When a bag is in place, slide No. 3 is opened. By changing the rate of vibration in the table, it is claimed that a difference of as much as eight pounds in weight may be obtained, and in each case have a sack well filled. The table is vibrated by an eccentric and shaft No. 5. When the bag is full it is simply pulled off, and thrown on the truck ready for shipment. The machine is intended for use on both paper and burlap or jute bags, but we cannot say just how satisfactory it has proven when using the latter.

Properties of Hydrated Lime.—The following table gives some of the properties of hydrated limes. From repeated tests of the specific gravity, it is evident that hydrated magnesian limes of good quality run from 2.12 to 2.25.

The loss on ignition represents the combined water, plus any carbonic acid which may have been absorbed. The latter is apt to be small in amount. The amount of combined water, or the loss on ignition, is, therefore, a measure of the degree of hydration. If the dolomite were pure, and its calcination and hydration perfect, the loss on ignition would be about twenty-seven per cent. We can safely assume that not more than ninety-five per cent of the theoretical purity and efficiency is to be found in commercial hydrates; this would correspond to a loss of 25.65 per cent. on ignition. Assuming that this figure represents the best that can be done commercially, the completeness of hydration accomplished in the product of some Ohio manufacturers was computed in a scale of 100, viz:

New Process lime	94
Standard rock wall finish	81
Standard rock wall finish (four months old)	75.6
White ivory finish	75
White rock finish	58

The difference between the old and new standard rock wall finish is no doubt due to hygroscopic moisture in the new product. Several attempts were made to determine the hygroscopic water in the various samples, but it was found that it could not be done without the setting up of elaborate apparatus, for which there was not sufficient time. From a practical point of view, the proof of the matter would be of small moment. Even the sample which showed the lowest degree of hydration was safely stored in paper bags, and after several months this sample showed no apparent change in volume.

Table XXX—Loss on Ignition and Specific Gravity.

Product.	Location from which sample came.	Magnesian lime.		High calcium lime.	
		Specific gravity.	Loss on ignition per cent.	Specific gravity.	Loss on ignition.
Air slaked lime	Genoa	2.66	13.11	....	....
Harrier process lime 4 hours after addition of water	Genoa	2.53	14.04	....	....
Harrier process lime 18 hours after addition of water	Genoa	2.27	20.47	....	....
Harrier process lime 24 hours after addition of water	Genoa	2.19	19.25	....	....
White Ivory finish	Genoa	2.35	19.28	....	....
New Process lime	Genoa	2.12	24.03	....	....
Quicklime	Genoa	3.15	0.22	....	....
Standard rock wall finish	Gibsonburg.	2.14	20.95	....	....
Standard rock wall finish, 4 months old	Gibsonburg.	2.25	19.40	....	....
*White rock finish	Clay Center	2.25	14.90	....	....
Hydrated in dry steam	....	2.68	....	2.46	....
Hydrated in moist steam	....	2.50	....	2.44	....
High calcium lime	Delaware	....	....	3.13	....
High calcium limestone	....	....	....	2.69	....

*This sample was purchased in Toledo, Ohio, as having come from Toledo White Lime Co., and sack was labeled "White Rock Finish, Tiger Brand."

Another line along which evidence was gathered in the study of hydrated limes is the relative increase of volume due to different methods of slaking and the different degrees of completeness reached. A series of experiments were made, as follows:

Samples of the various limes were ground and weighed. All the water to be used was added at once, and vigorous mixing continued until the end was reached. The time required to reach the end was approximately twice as long with the magnesian lime as with the hot lime. When slaking was complete, the resultant hydrate was dried, pulverized, and sieved, and the volume was measured in a graduate after they had been jarred down to a comparative uniformity of compactness.

The increase in volume was distinctly in favor of the high-calcium lime, as was to be expected, since the oxide of magnesia would under such circumstances take up very little water of hydration, and would, consequently, not add its full share to the expansion of the whole mass. The expansion shown by the dolomite lime was, however, greater than could be accounted for by the calcium oxide present.

The results are given in the following table:

Table XXXI—Physical Tests of Ohio Limes.

Kind of lime.	Volume in cc. of ground quicklime used. 25 grams in each case.	Volume in cu. cen. of water added.	Volume in cu. cen. of hydrate produced.	Tensile strength of mortar after 7 days. Mortar made by adding 100 cc. sand 4 volumes of sand to 1 volume quicklime.	Remarks.
High calcium ..	27.5	7.	65	48.95	Water 20% less than theory for complete hydration.
	27.5	9	80	70.6	Theoretical amount of water.
	27.5	10.5	98	....	20% excess.
	27.5	12.	100	....	40% excess.
	27.5	17.5	92	59.	100% excess. Product, moist powder
	27.5	17.5	98	42.36*	*Broke badly. Defective briquette. 100% excess. External heat applied when slaking.
	27.5	27.	60-65	48.95	200% excess. Moist, lumpy mass.
	27.5	36	40	65.90*	*Briquette cracked lengthwise before going in machine. 300% excess. Smooth, stiff putty.
Dolomite lime..	29	8	85	24.48*	*Bad briquette. 20% less than theory for complete hydration.
	29	10	90	77.2	Theoretical amount of water.
	29	12	80	58.	*Bad briquette. 20% excess.
	29	14	72	81.90	40% excess.
	29	20	....	82.84	Sticky, lumpy mass. 100% excess.
	29	20	80	....	External heat applied during slaking. Moist powder produced 100% excess.
	29	30	35	68 *	*Bad briquette. Stiff putty. 200% excess.

With steam slaking, the increase in volume of dry powder was for high-calcium limes about 2 to 2.5, for magnesium limes from 1.75 to 2.00. The steam slaked samples all showed appreciable amounts of carbonic acid, which was no doubt introduced with the steam; the specific gravity also indicated that hydration was not so complete as with other methods. The absorption of carbon dioxide would have the same influence on the specific gravity as water.

With imperfect slaking, it is very probable that the presence of magnesium oxide is responsible for a deficiency of water below the theoretical, since magnesium oxide is of necessity overburned, so far as its sensitiveness to water is concerned, before the calcium oxide is produced. This does not mean that these limes are inferior. The fact that dolomite limes under ordinary slaking conditions do not take up so much water as the high-calcium limes does not seem to have any influence on the strength of mortars produced In fact, such meager data as have been published show the dolomite limes as developing much the greater tensile strength of the two, especially after six months or more. The following results obtained by Geo. S. Mills, of Toledo, and published in advertising literature, and in *Municipal Engineering*, vol. 28, pp. 4-7, are very much in favor of the magnesian or dolomite limes. The results as given are averages on five or six briquettes.

The dolomite lime used was practically a pure dolomite. The high-calcium lime was one containing about nine per cent. of magnesium oxide. Two parts of sand to one part of slaked lime by weight was used in each case in making the briquettes. Tensile strengths are expressed in pounds per square inch.

Table XXXII—Tensile Strength, High-calcium vs. Dolomite Lime.

Lime used.	Time period.					
	4 weeks.	8 weeks.	3 months.	4 months.	6 months.	1 year.
High-calcium lime..............	30.66	36.40	39.25	39.00	50.84	44.60
Dolomite lime	.....	28.84	37.16	51.00	83.00	92.84

The "New Process Lime" is allowed to ripen in the putty form for twenty to thirty days. Since, even after this long soaking, hydration is incomplete, it is a very safe conclusion that mechanical slaking to a dry powder gives as complete hydration as is obtained in the ordinary slaking of dolomite limes for mortar purposes.

The tensile strength of the limes produced by the various materials and various methods of slaking was studied in a hasty manner. Much work remains to be done on this subject before authoritative statements can be made.

In making the mortar for the briquettes, that prepared from the high-calcium lime was first mixed up. Slightly more water than was desirable was used, and some difficulty was experienced in getting briquettes that were not distorted. With the dolomite limes, less water was used and briquettes of better form were obtained. This was partly due to the general tendency of dolomite limes to give a firmer mortar than the other type of lime. It is rather difficult to obtain perfect briquettes with lime mortars of ordinary consistency.

While the results as they stand are distinctly in favor of the dolomite limes for strength, the writer does not consider this test at all conclusive, on account of the low tensile strengths of all the mixtures tested, and the errors bound to be introduced by imperfect and distorted briquettes. A safe conclusion could only be drawn by making a large number of briquettes, and breaking quite a number at each time period, carrying the work out through a number of years. This, if properly carried out, offers a method of proof for the much disputed question as to which kind of lime makes the best and strongest mortar.

Public opinion and trade conditions are not exactly in harmony on the question. A great many people will claim that the dolomite limes are the best for all purposes, and among the smaller users of lime the great majority prefer the so-called white lime. For white or "skim coat" work, it is best, since, as a rule, it is whiter than most of the hot limes burned in Ohio. Bricklayers say they prefer it to hot limes, because they have less trouble in keeping their mortar in condition; i. e., the mortar can be spread before it is necessary to lay up the brick. They claim that the mortar, once in proper condition, does not change or harden so rapidly as that made from hot lime.

On the other hand, there are many who claim that the hot lime will carry more sand. In all large cities, there are now mortar factories, whose sole business is to prepare mortar for use in construction; they make any and all kinds of mortar, for foundations, for brick walls, for plastering, colored mortars for face brick, etc. These firms, who make mortar by the hundreds of tons, naturally are in a position to study the relative value of every different ingredient entering their mixtures. The large amount of material handled should give the opinion of mortar manufacturers weight. The mortar manufacturers invariably use moderately hot or quite hot limes as the basis of manufacture, adding considerable quantities of the dolomite lime to "temper down" the mortar, "make it harden more slowly," as they say, and give it a better body. They claim better results from a mixture of the two hydrates than with either alone. More dolomite lime is used in the mortar for plaster than in that for masonry.

Another fact in favor of high-calcium over the dolomite limes is that of all the lime burned in Ohio about one-half of it comes from limestone carrying over seventy per cent. calcium carbonate. In Bulletin 5 of this series, on sand-brick, it is proved very conclusively that the high-calcium limes are best for that purpose.

The following table gives results on four mixtures of sand and lime which are exactly comparable. These were rather dry mortars, formed under moderate pressure in the molds of a screw hand press, and allowed to harden in the air for forty-six days. They were then crushed and broken in a tensile testing machine.

Table XXXIII—Comparison of Dolomite vs. High-calcium Limes.

Dolomite lime.			High calcium lime.		
Number.	Crushing strength.	Tensile strength.	Number.	Crushing strength.	Tensile strength.
76 (a)	578	43	73 (a)	656	21
59 (a)	522	61	65 (a)	670	41
Average	550	52	.....	663	31

From the above it would seem that neither has any decided advantage, one being higher in crushing strength the other in tensile strength.

These figures, however, are very suggestive. They seem to indicate that the reaction with the high-calcium lime is entirely one of carbonate formation, but with the dolomite lime some secondary reaction like the formation of a sorel cement in a chemical union has set in—a chemical union or interlocking of the various magnesium and calcium compounds, which increases the tensile strength. This is not improbable, since there are present, no doubt, magnesium oxide, magnesium hydroxide, magnesium carbonate, calcium hydroxide and carbonate as well as some sulphates. If there were no secondary reaction, the crushing strength and tensile strength should bear the same general relation to each other in both cases.

In the small amount of experimental work which has been done thus far in examination of limes, in the opinion of the writer, sufficient attention has not been given to details, so that results as they stand today are not altogether comparable. In planning work of this sort, the properties of both rich and lean mortars should be examined, the physical character of the sand used, the size of grain and the amount of voids in the sand in each case should be observed, both crushing and tensile strength tests should be made, since there seems to be a difference in the nature of the reaction during hardening, when different limes are used. The amount of shrinkage in drying is also a matter of importance when trying to determine the quality of any mortar. In any test of this sort on account of the low breaking strength which makes the percentage error for manipulation greater than if working with stronger materials, it is necessary that quite a number of pieces be broken or crushed for each test.

Unsolved Problems.—There are many unsolved problems in the lime industry, both to the manufacturer and the scientist. Some few of them are indicated as follows:

First: How to utilize the fine limestone which accumulates about most lime plants.

Second: How to get the most economy out of fuel.

Third: What new uses can lime be put to in order to maintain production, in view of the increasing use of hard-wall plasters in place of the old mortar plasters?

Fourth: How can further and more conclusive evidence be produced to show the relative values of the different limes for any given purpose?

Fifth: Does the sorel cement reaction enter as a factor in the strength of dolomite lime mortars?

Sixth: How can complete hydration of dolomite limes be accomplished on a commercial scale?

Seventh: What is the behavior of limestone and dolomite calcined at temperature beyond 1200° C.?

Eighth: What is the behavior of magnesite calcined at temperatures from 350° C. up, by steps of not over 50° C. each?

Many more might be cited, but the foregoing are sufficient to show how nearly untouched is this field of research.

APPENDIX.

The following pages contain descriptive matter and drawings of some of the typical lime manufacturing establishments of Ohio. The information in each case is authentic, having been obtained in some cases from drawings furnished by the companies, in other cases by actual measurements on the spot, and where possible these drawings have been revised and criticized by the managers of the respective plants. The small amount of literature in the English language on the engineering of the lime industry should make this accumulation of data of the highest value. The broad-gauged liberality and open-minded attitude shown by the various companies concerned is the best possible evidence of the progressive spirit now prevailing in the lime industry.

THE SENECA WHITE LIME COMPANY.

The Seneca White Lime Company, of Fostoria, Ohio, is the only one of its kind in the state. It is exceptionally well built throughout. This plant was designed by the manager, Mr. W. S. Sutliffe, after many years of experience in the lime business. The plant, as the plans show, is built almost entirely of brick and iron, and is to all intents and purposes a fireproof plant.

While natural gas is the fuel at the present time, the plant is equipped with coal conveyers which will deliver coal from a conveyor passing between the two rows of kilns, as seen on the plan, with a swinging delivery, so that coal can be delivered to each kiln. It should also be noted that these kilns are not put up in close battery form, but that on the firing floor the entire circumference of each kiln is accessible and that three furnaces have been placed in each kiln, at equal distances apart on the circumference. These kilns are much higher than the average kiln.

This plant was built in 1899 and 1900, and shortly after its erection mechanical stokers were tried on each of the kilns. The management finally gave it up because they could not get the draft through satisfactorily, and the flames and gases would back up and blow out of the furnace doors when drawing. Mr. Sutliffe makes the following suggestions, or criticisms, with reference to these kilns provided he were building again:

"The fire arches should be low—not over eighteen inches high at the crown. These should be nothing but a circular kiln with four furnaces. The top of the kiln should be flared to about eight feet in diameter at the extreme top, starting at the narrowest point in the kilns, where the diameter is five feet six inches to six feet. The present height of the kiln is too great for satisfactory operation without the use of induced draft. Thirty feet above the grate bars would be about right."

This plant has a kiln capacity of about eighty-five barrels per day, and the drawing is done every four hours. The natural gas is brought in through a six-inch main line, with a two-inch line to each burner. The gas pressure is reduced by a gauge to about eight-ounce pressure, as this seems to give the best results. When burning very fine stone a still lower pressure than this seems to be advisable. The burner consists of a piece of pipe two inches in diameter by three feet long, which is fitted into the furnace formerly used for coal. The rear end of this is supplied with a gas jet about thirteen thirty-seconds of an inch in diameter at the nozzle and a steam jet about one-sixteenth of an inch in diameter at the nozzle, which delivers steam at ordinary boiler pressure. With this gas pressure and this size of nozzle it is not very difficult, by regulating the valve, to maintain the long blue flame desirable for lime-burning purposes. Each kiln, working under normal conditions, requires about one-half cubic yard of gas per second. By the use of natural gas the power and labor required for handling coal, both for lime-burning and for power purposes, as well as the labor of about three men at the plant, is saved.

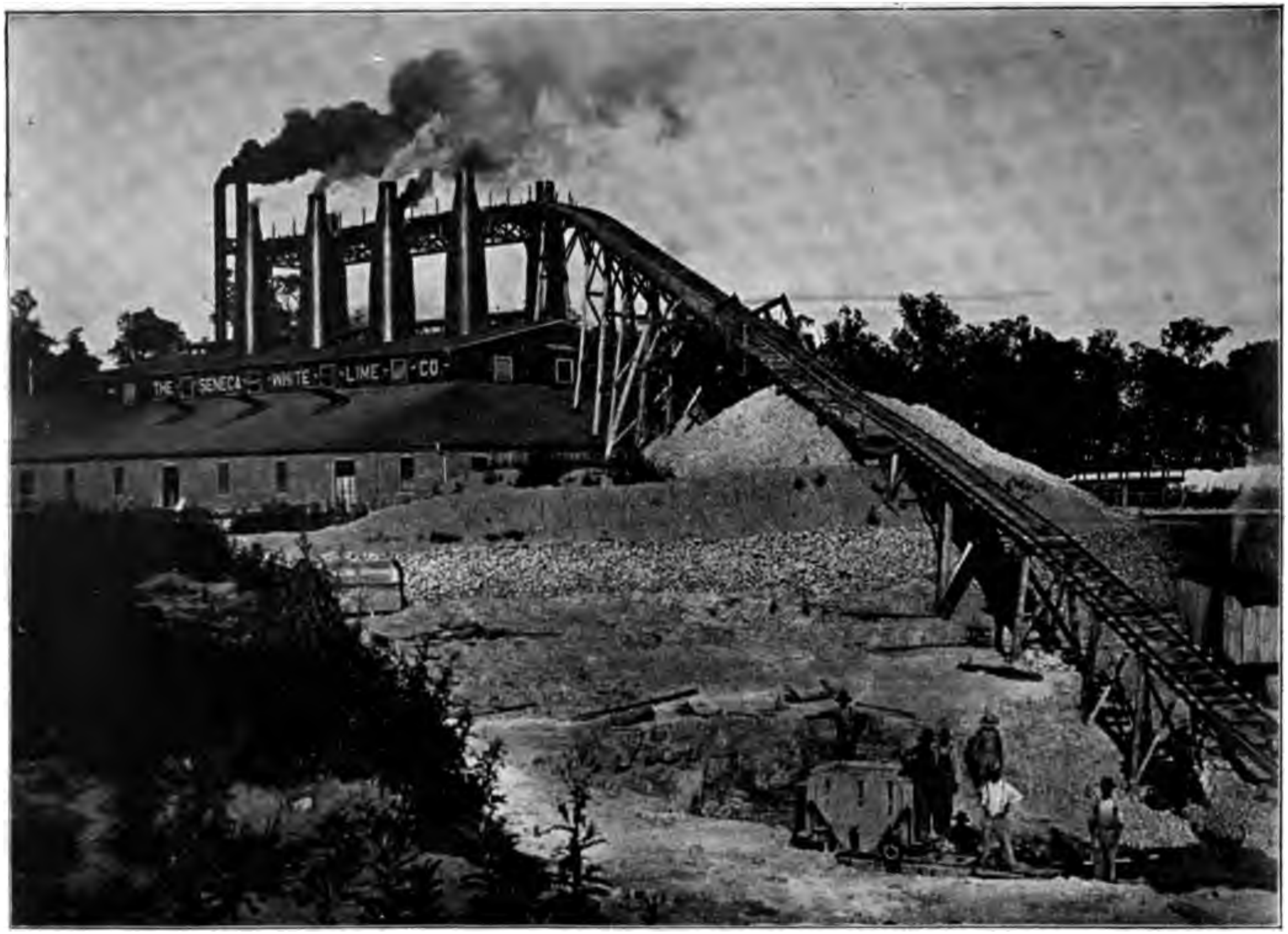


Figure 36.—General view of works of the Seneca White Lime Company, of Fostoria, Ohio.

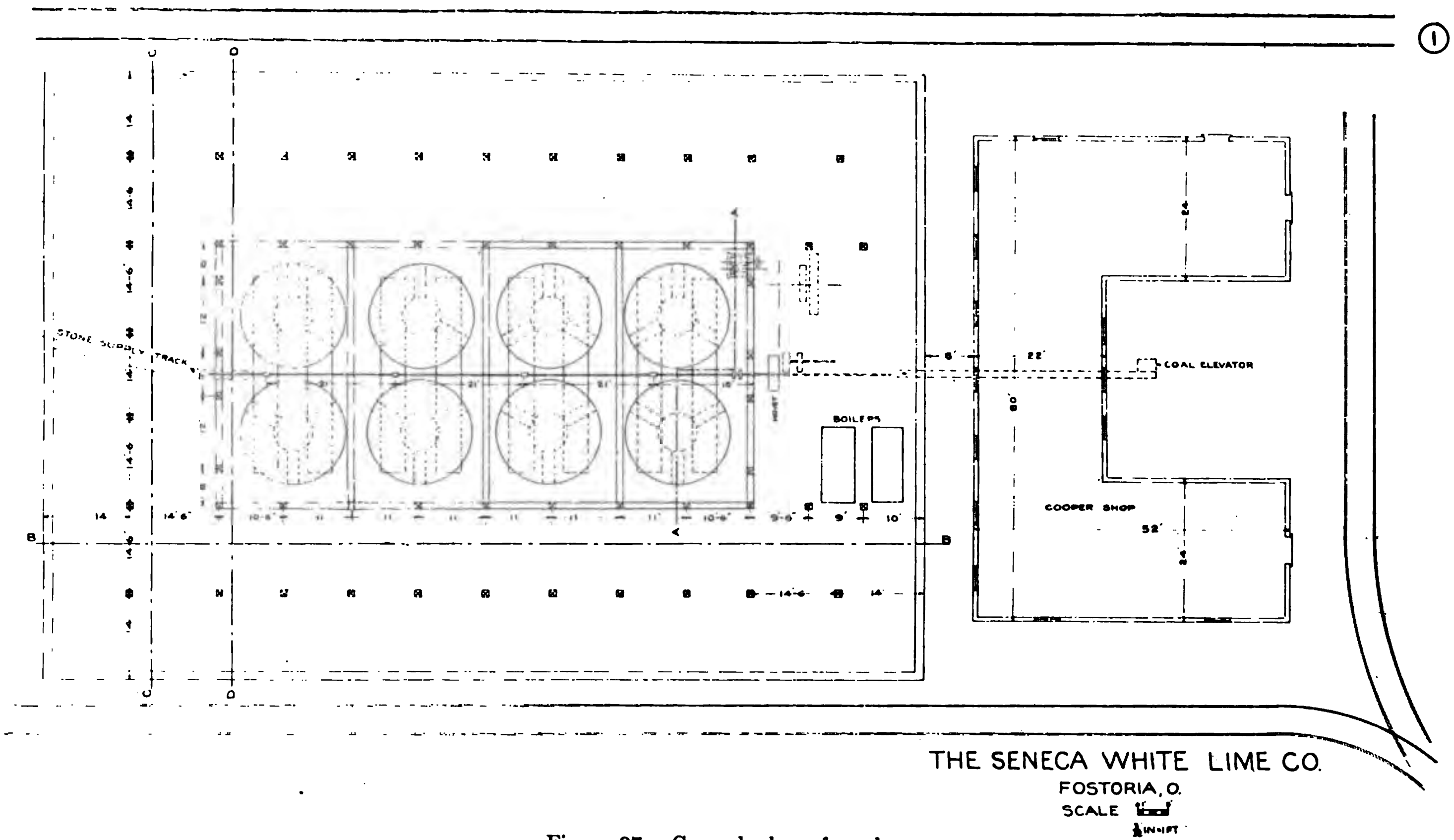


Figure 37.—Ground plan of works.

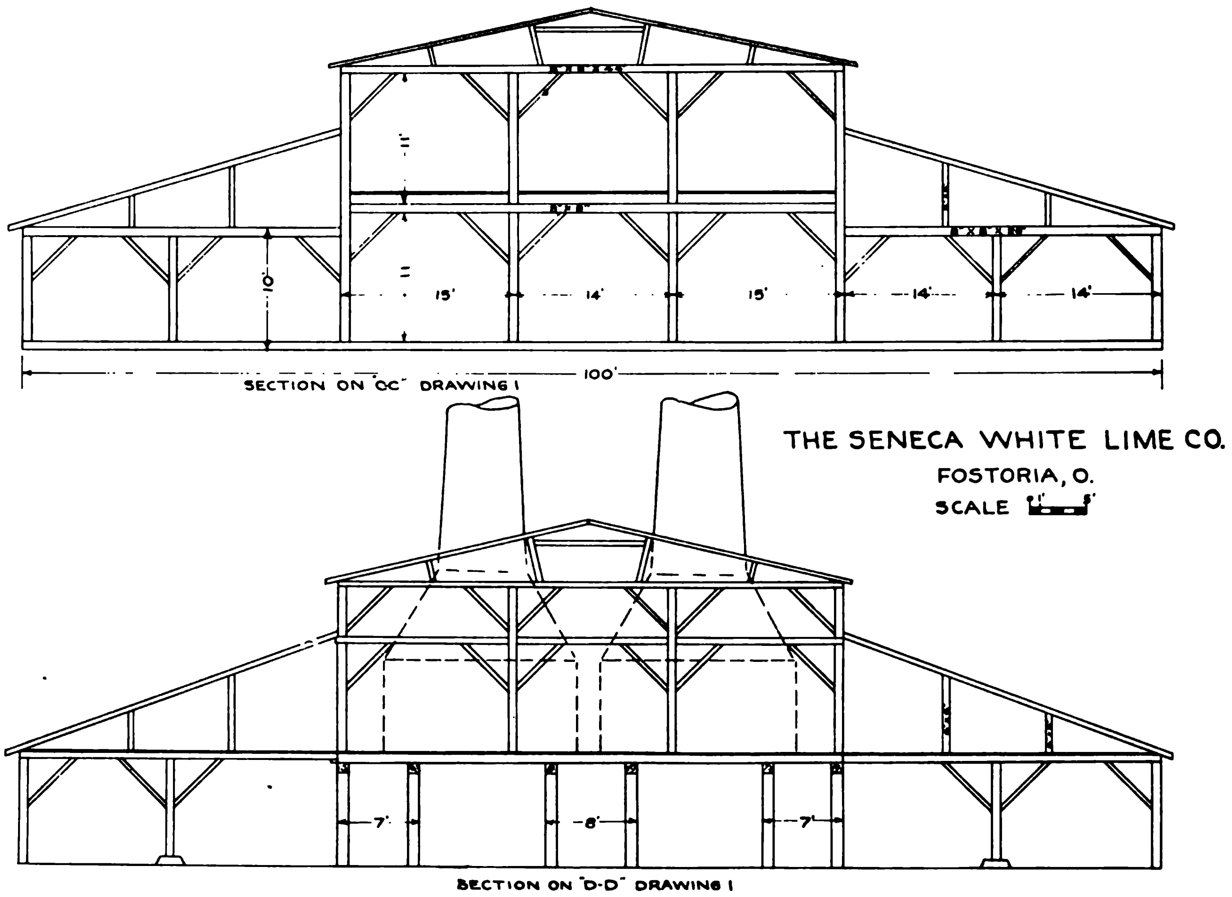

11'
11'
10'
15'
14'
15'
14'
14'
100'
SECTION ON "C-C" DRAWING 1
THE SENECA WHITE LIME CO.
FOSTORIA, O.
SCALE 0 1' 5'
7'
8'
7'
SECTION ON "D-D" DRAWING 1

Figure 38.—Cross section of buildings of Seneca White Lime Company.

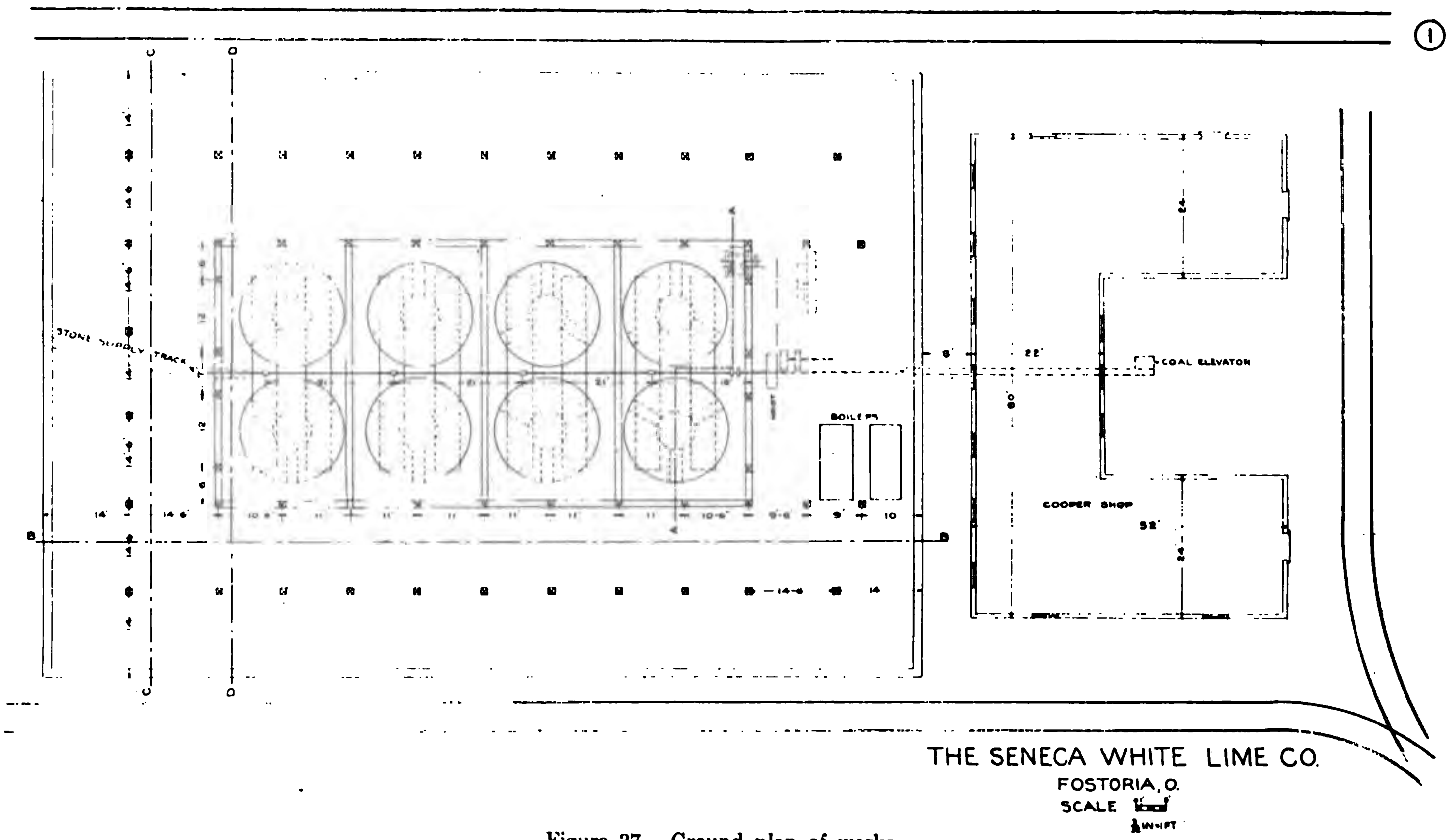
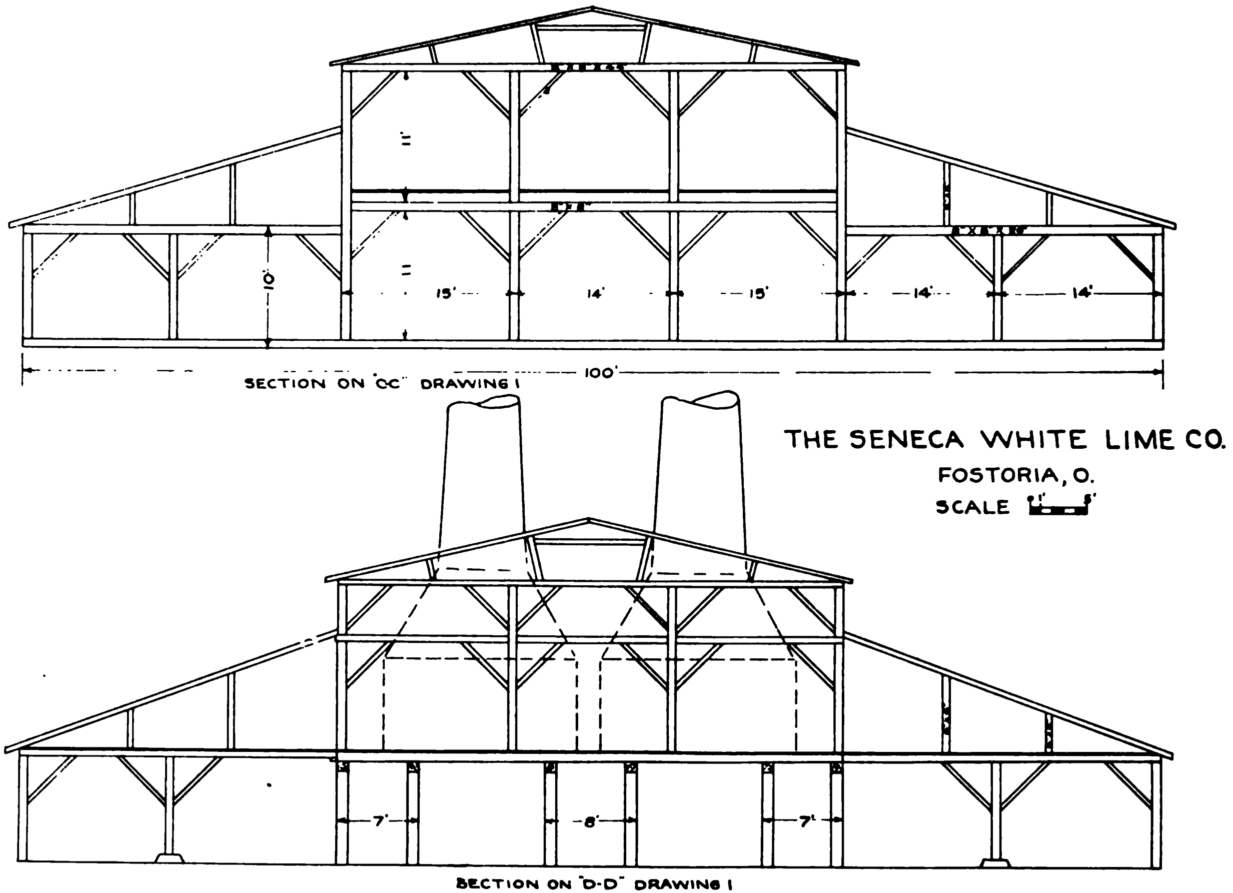


Figure 37.—Ground plan of works.


15'
14'
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10'
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11'
100'
SECTION ON "CC" DRAWING 1
THE SENECA WHITE LIME CO.
FOSTORIA, O.
SCALE
7'
8'
7'
SECTION ON "D-D" DRAWING 1

Figure 38.—Cross section of buildings of Seneca White Lime Company.

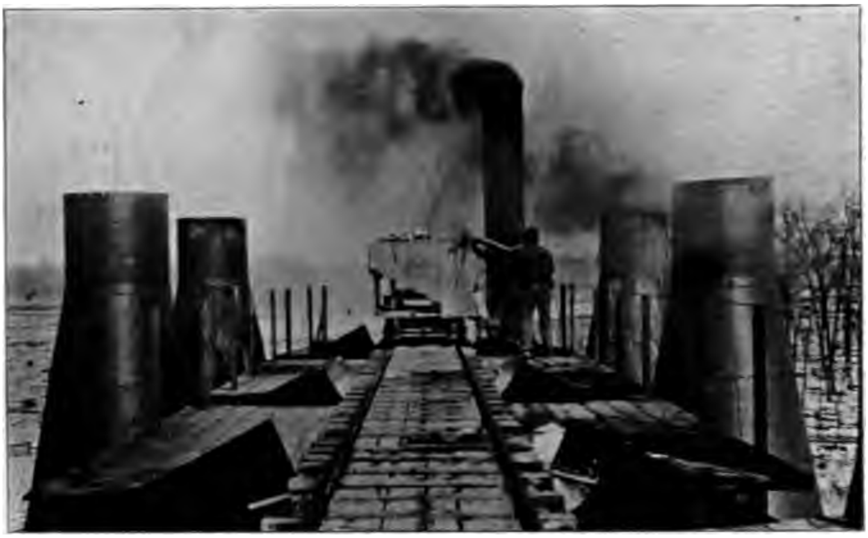


Figure 41.—View of top of kilns and charging track. Seneca White Lime Company.

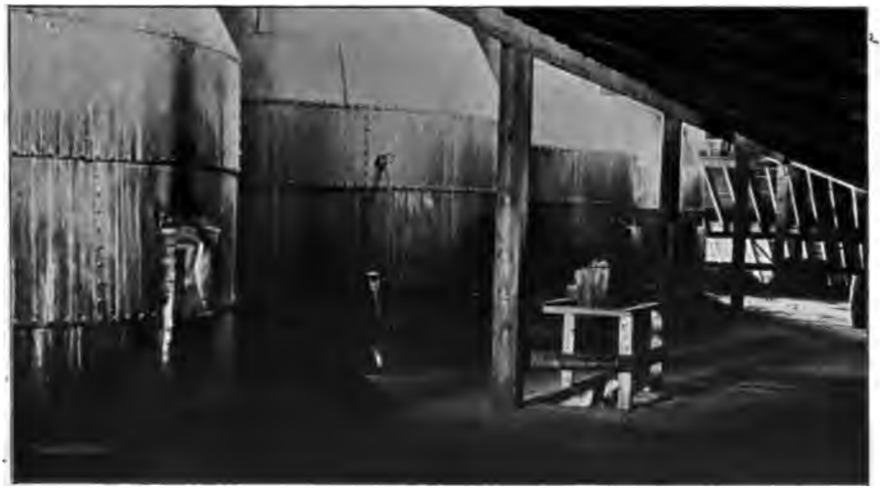


Figure 42.—View of kilns at level of firing floor. Seneca White Lime Company.

THE SCIOTO LIME AND STONE COMPANY.

The plant of the Scioto Lime and Stone Co., the plans of which are herewith given, is located near Delaware, Ohio, and is connected with the Big Four railroad by a siding. This plant is one of recent construction, haying been built entirely new since the Report of 1888 on the Lime Industry. This plant was begun in 1899 by James Reaney, Jr., and Francis Starr, by the opening of a quarry and the construction of three kilns. In 1901 two more kilns were added, and in 1902 Mr. Reaney purchased Mr. Starr's interest and Mr. H. E. Kendrick became treasurer and manager of that company and still remains in that capacity. In 1903 three more kilns were added, making it today an eight-kiln plant. As the plans will show, the kilns in use at this plant are of oblong section, with four furnaces to a kiln, with rather short stacks. The fuel economy shown by these kilns is about the average for coal and natural draft. The kiln capacity, as shown by the daily record, is rather above the average. This is the only plant manufacturing high-calcium lime, which is illustrated in detail. In 1905 this plant was equipped with the American Hydrating Company's machinery, which gives them a capacity of six to eight tons per hour of hydrated lime. In 1906 steel storage bins with steel covers and steel encased conveyors were installed. The bins have a capacity of about one hundred and fifty tons, while the total storage capacity of hydrated lime is about twenty-five cars. As is indicated on the plan, the coal for the kilns comes in on one side and is delivered from a track on a level with the firing floor, while the finished product is delivered on the opposite side to tracks at a convenient loading level. This plant has its cooperage storage, and cooperage shop, adjacent to the main plant. The management contemplates the installation of a crusher to take care of materials too small for the kiln. The product manufactured is as high or higher in calcium oxide as any produced in the state. In consequence it is hot and quick slaking.

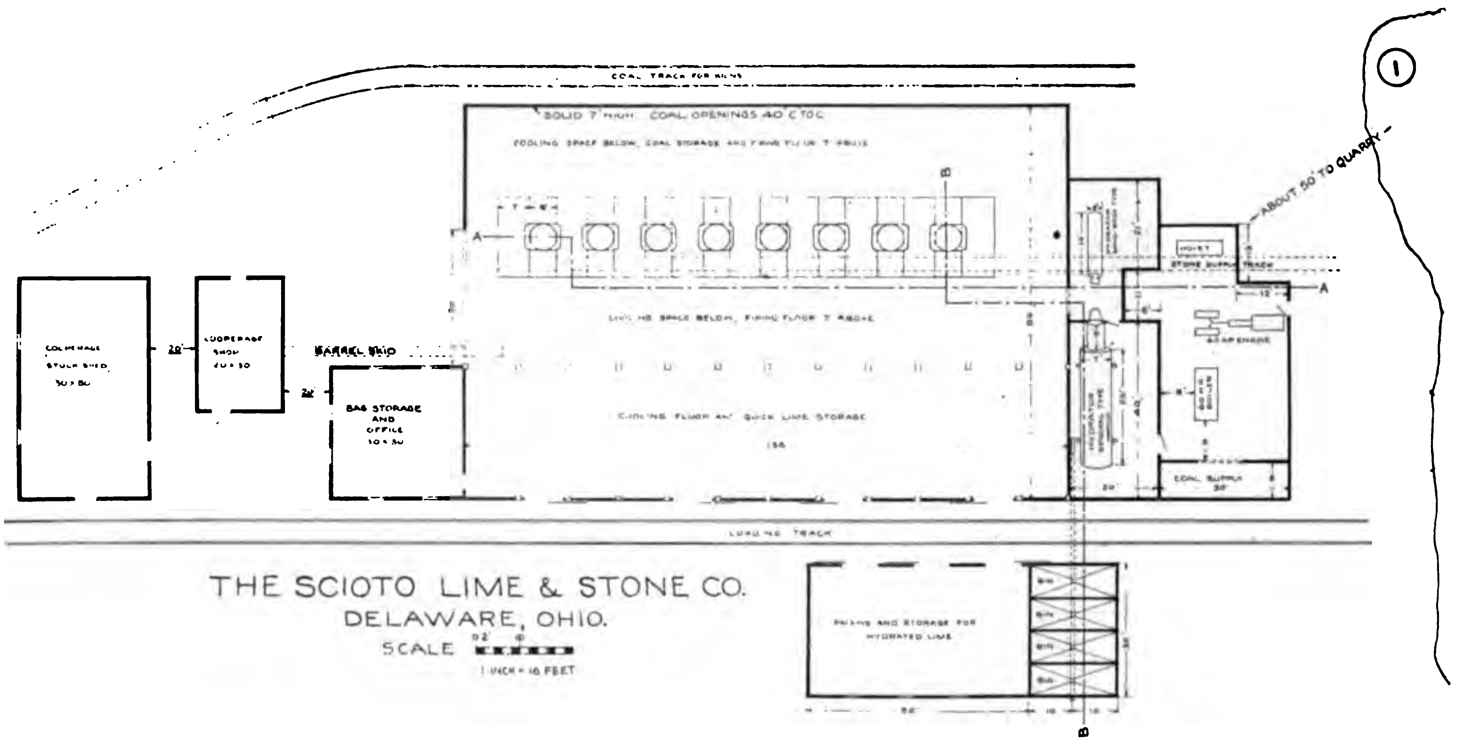

COAL TRACK FOR KILNS
SOLID 7' HIGH COAL OPENINGS 40' C TO C
COOLING SPACE BELOW, COAL STORAGE AND FIRING FLOOR 7' ABOVE
COOLING SPACE BELOW, FIRING FLOOR 7' ABOVE
COOLING FLOOR AND QUICK LIME STORAGE
156
A
B
58
HYDRATOR SPECIAL TYPE
HOIST
STONE SUPPLY TRACK
ABOUT 50' TO QUARRY
12
6'
40 HP ENGINE
60 H.P. BOILER
8'
COAL SUPPLY
30'
20'
40'
24'
①
LOADING TRACK
PACKING AND STORAGE FOR HYDRATED LIME
BIN
BIN
BIN
BIN
52'
10
10
30
COOPERAGE STOCK SHED 30 x 80
20'
COOPERAGE SHOP 20 x 30
BARREL SKID
24'
BAG STORAGE AND OFFICE 30 x 30
THE SCIOTO LIME & STONE CO.
DELAWARE, OHIO.
SCALE
1 INCH = 16 FEET

Figure 43.—General ground plan.

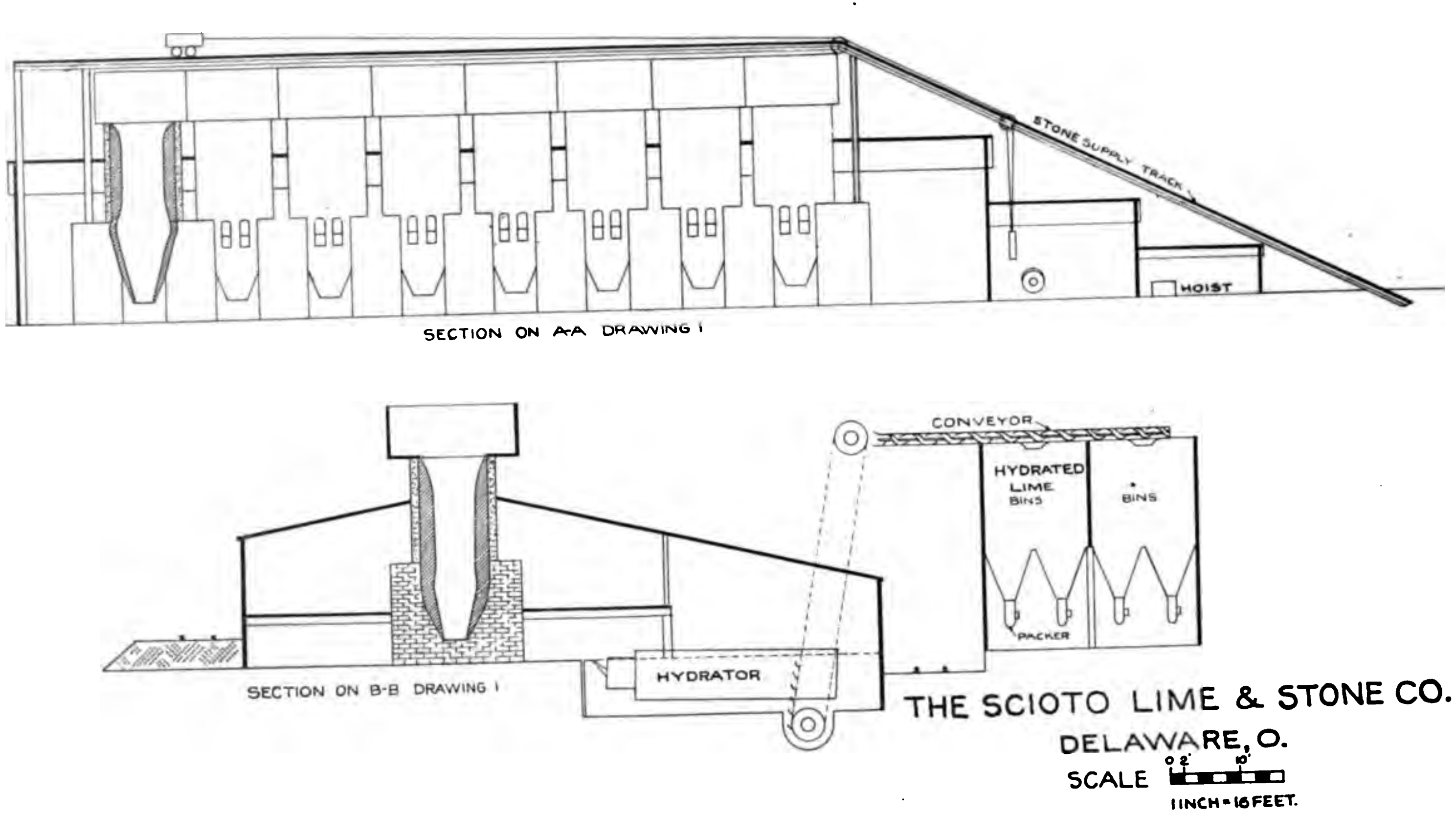


Figure 44.—Longitudinal and cross section.

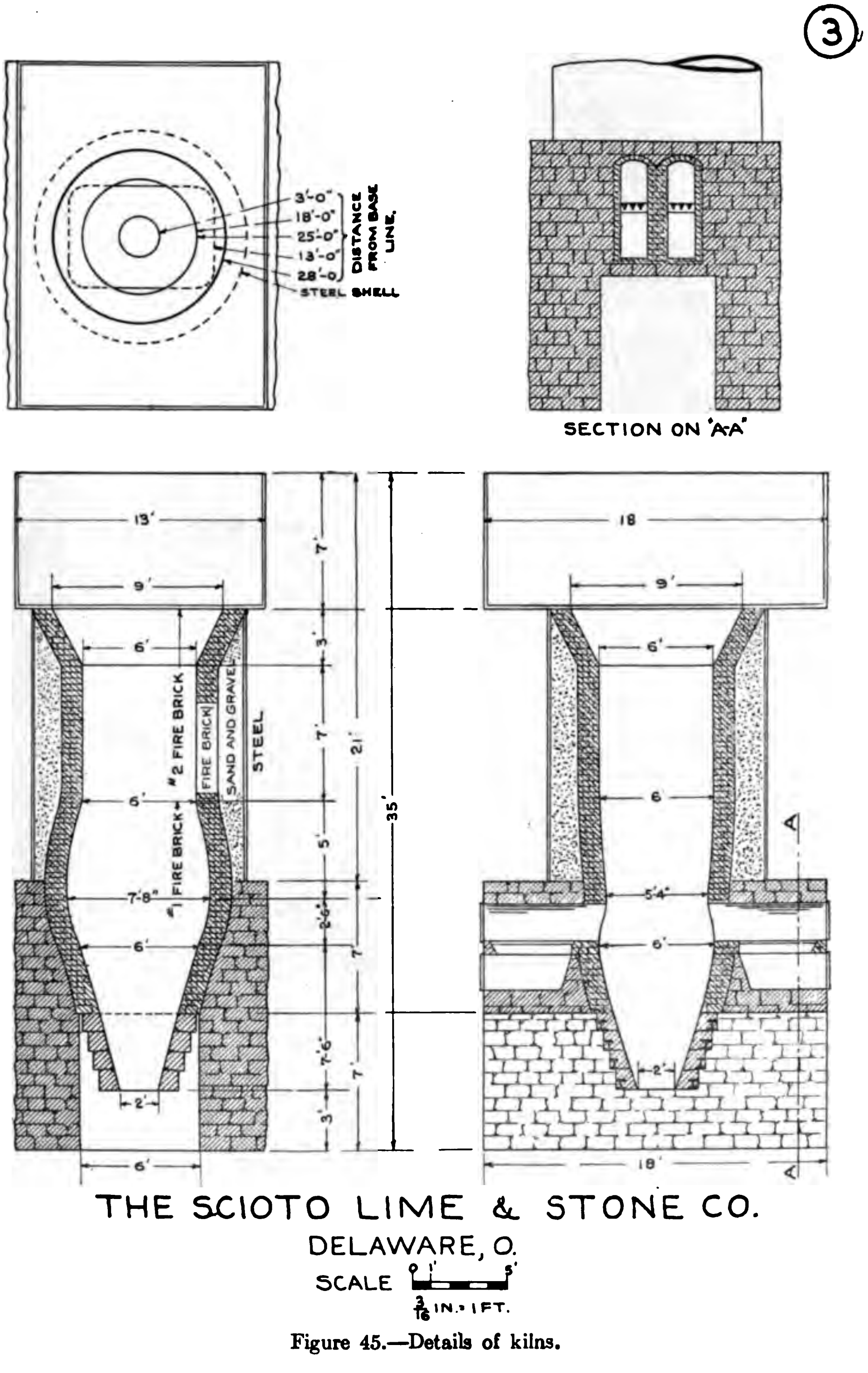


Figure 45.—Details of kilns.

THE WOODVILLE WHITE LIME COMPANY.

The plant of the Woodville White Lime Company is another one of recent development. The present management took hold of this plant four or five years ago, and immediately began its reconstruction. The quality of the stone available had been well demonstrated, because this had been the site of a couple of small kilns for many years. These kilns had been practically abandoned when the present management took hold of it, not because of lack of material or undesirable quality of material, but because of a lack of energy—or rather of business aggressiveness—and a lack of capacity sufficient to justify entering the broader market, which the centralization of lime interests made it necessary to do in order to make a financial success. The present management, on the other hand, as soon as they acquired the property, became aggressive in the broader market, and at once began spending money in the way of plant improvements, as well as in the development of side lines, such as dry mortars ready mixed for use, special white coat, which had dolomite lime as a base, and things of that sort. At one time this firm was even manufacturing quite a good deal of hard wall plaster which carried a very large per cent. of calcined gypsum. This firm was also one of the earlier producers of hydrated lime, and as the plans will show, they are today running two of the large Clyde hydrators, of which they speak very highly after having had them in use for some time. This company has had some experience with other hydrating machines, and suit was brought against them on one occasion and as a result of this suit several patents are today considered valueless that up to that time had been the means of bringing their owners some royalty.

As another illustration of the progressiveness of this firm, it was the first in the United States to adopt the Bates valve bag packer for the purpose of packing hydrated lime into sacks. While this machine had not been in use very long at the time of the writer's observation, it seemed to have merit enough to justify a brief description here as a new item in lime technology. This company spoke very highly of this method of packing. (See illustration and description, page 334.)

This plant is using rather low, flat, closed-top kilns and induced draft and have rather short brick coolers at the bottom. The fuel efficiency obtained is about the average for the state, and showed exceptionally good management, since their heat losses due to drawing the lime very hot are bound to be great and must be overcome by careful management in other directions. In the opinion of the writer it would pay very well to materially increase the height of these kilns if induced draft is to be used. He also believes that this is the first plant in the state to completely inclose the tops of the kilns and apply suction by mechanical means near the tops of the kilns for the purpose of increasing the draft and thereby increasing the capacity. The type of kiln, however, which had proved successful with natural draft was not modified to meet new conditions, except that steel cases were put on the kiln, with horizontal tops having folding doors, which are laid back for the purpose of dumping in limestone.

This plant has grown rapidly in the last few years, and additions have been made from year to year, and it is hardly fair to presume that a plant which has come to its present size by additions at intervals would be exactly what its owners would like to see if they were to build an entirely new plant of the same size and capacity.

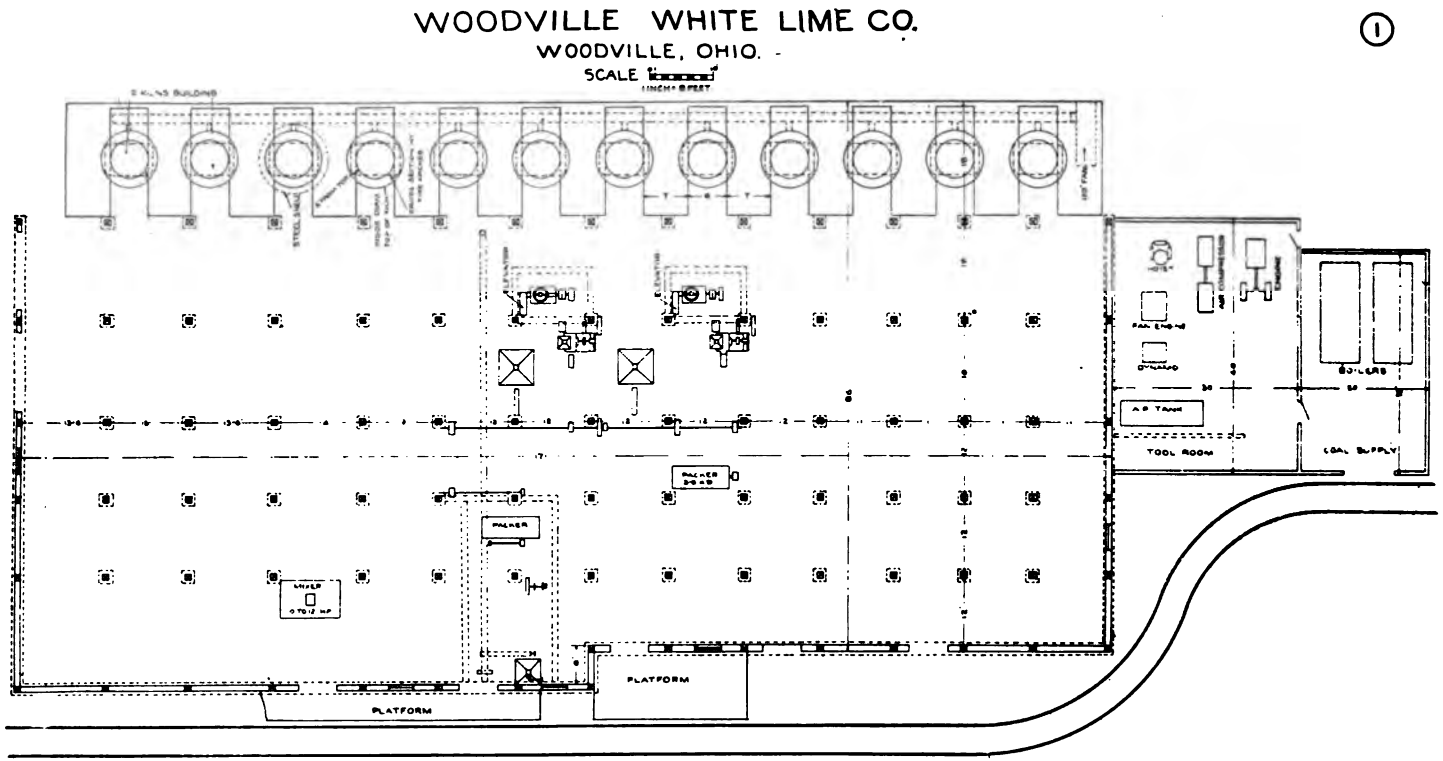


Figure 46.—General ground plan.

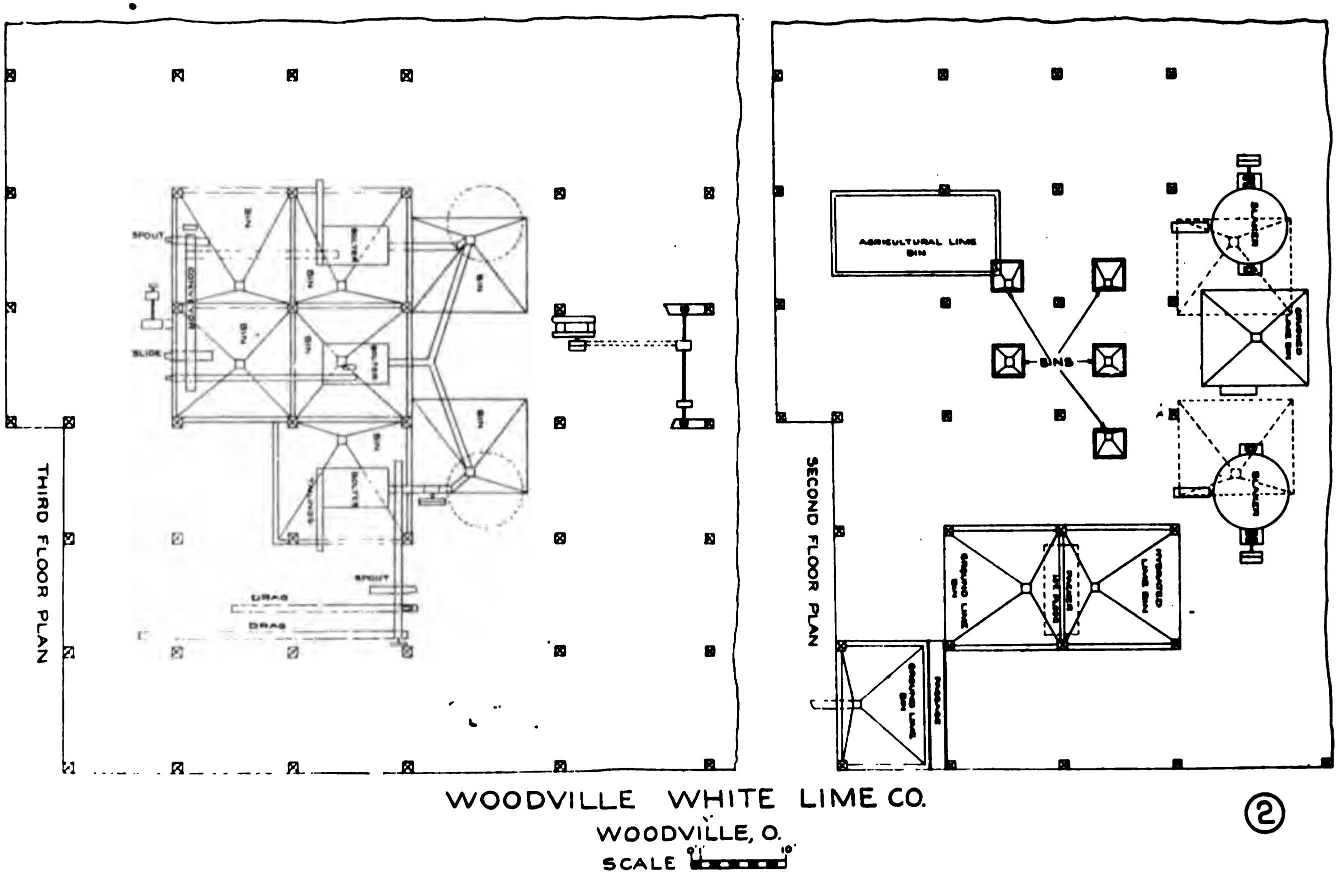


Figure 47.—Second and third floor plans.

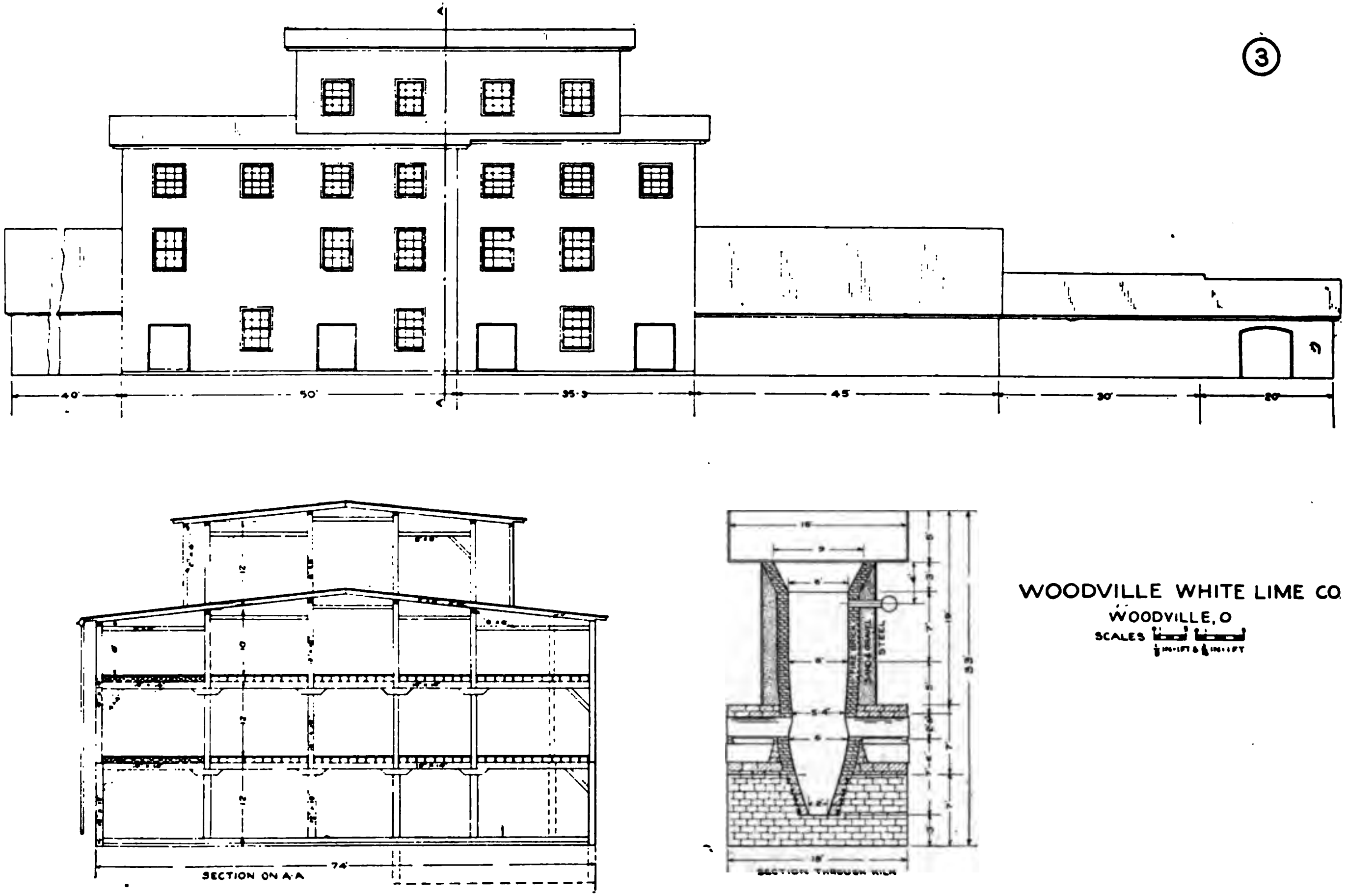


Figure 48.—Elevation and cross sections of buildings and kilns.

THE STANDARD LIME COMPANY.

The plant of the Standard Lime Company, at Gibsonburg, is one of the most recent construction in the state. It is also one of the best and most substantially built plants in the state, although not the largest in capacity. It certainly represents the most modern construction in the state. This plant is undoubtedly showing the highest fuel efficiency obtained at any plant in the state, when averages are taken through any long period of time. As the plans will show, the kilns represent the extreme as to height and as to small diameter. It is probable that with the use of producer gas, as is the practice at this plant, the diameter of the kilns could be increased to advantage and larger kiln capacity obtained without increasing the fuel cost per ton of lime produced.

The various Gibsonburg lime plants which have developed into the Standard Lime Company during the last fifteen years have spent a great deal of money in experimenting in methods and given close study to the introduction of various economies in lime manufacture. It was one of the first to try the continuous kiln, or "ring-ofen," and also one of the first to abandon it as not feasible in this country for lime manufacture. Following this a plant was started on the same site, with kilns approximating in type those now in use. A few years ago this plant was destroyed by fire and the present plant built at once. This plant, as well as the old one, has been the scene of very extensive experiments as well as successful development in the way of improvements in lime-hydrating machinery by Mr. A. H. Lauman, of Pittsburg. Mr. Lauman has here developed hydrating and separating machinery which is continuous in operation. This is certainly the right idea wherever it is successfully carried out, and is preferable to intermittent working.

While this plant was not the first in the state to introduce gas producers for the purpose of lime burning, it seems to have made a better success of it than the pioneer plant did—or, in other words, the fuel efficiency shown is better than that obtained at any other plant. During the last six months the monthly records of fuel cost have shown a gradual increase in fuel efficiency, until today they have passed the mark of four and one-half pounds of lime produced for a pound of fuel. This shows that with modern equipment and intelligent handling money can be saved in the cost of lime production as well as in the cost of any other manufactured commodity, by the application of accurate knowledge of the business as well as a knowledge of the principles which have proven money-savers in other industries.

It is gratifying to note that this location, which has been the scene of so much expenditure on experimentation, should ultimately be able to show the greatest efficiency in the state on fuel costs.

The producer in use at this plant is one manufactured by the Duff Patents Company, of Pittsburg, Pa., and is known as a water-seal producer, (see page 278.) Up to the present time but one producer has been installed for this purpose within the state. but at the present writing another producer and three more kilns than those shown in the plans are under construction. The plant, as the plans show, has two large hydrating machines, which are entirely enclosed, and the whole plant is constructed so as to be one of the cleanest plants in the state, because wherever it is possible lime dust is carefully confined. The construction of the entire plant is of the most substantial sort, and it probably has the finest power plant to be found in any lime plant in the United States. The entire power is taken from a Corliss engine, which even supplies power by means of a rope drive to a crusher which is located some distance from the engine, and was only recently installed to crush the smaller quarry spalls.

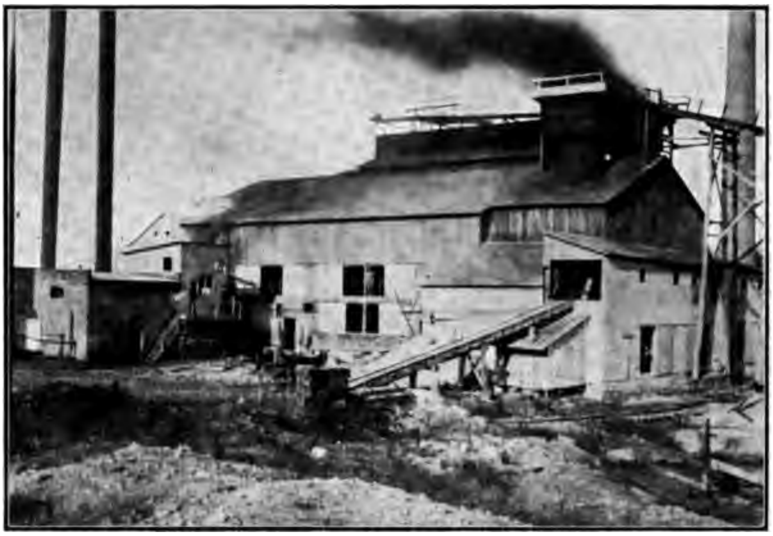


Figure 49.—Old plant of the Standard Lime Co., destroyed by fire. The scene of much successful experimenting in lime technology.

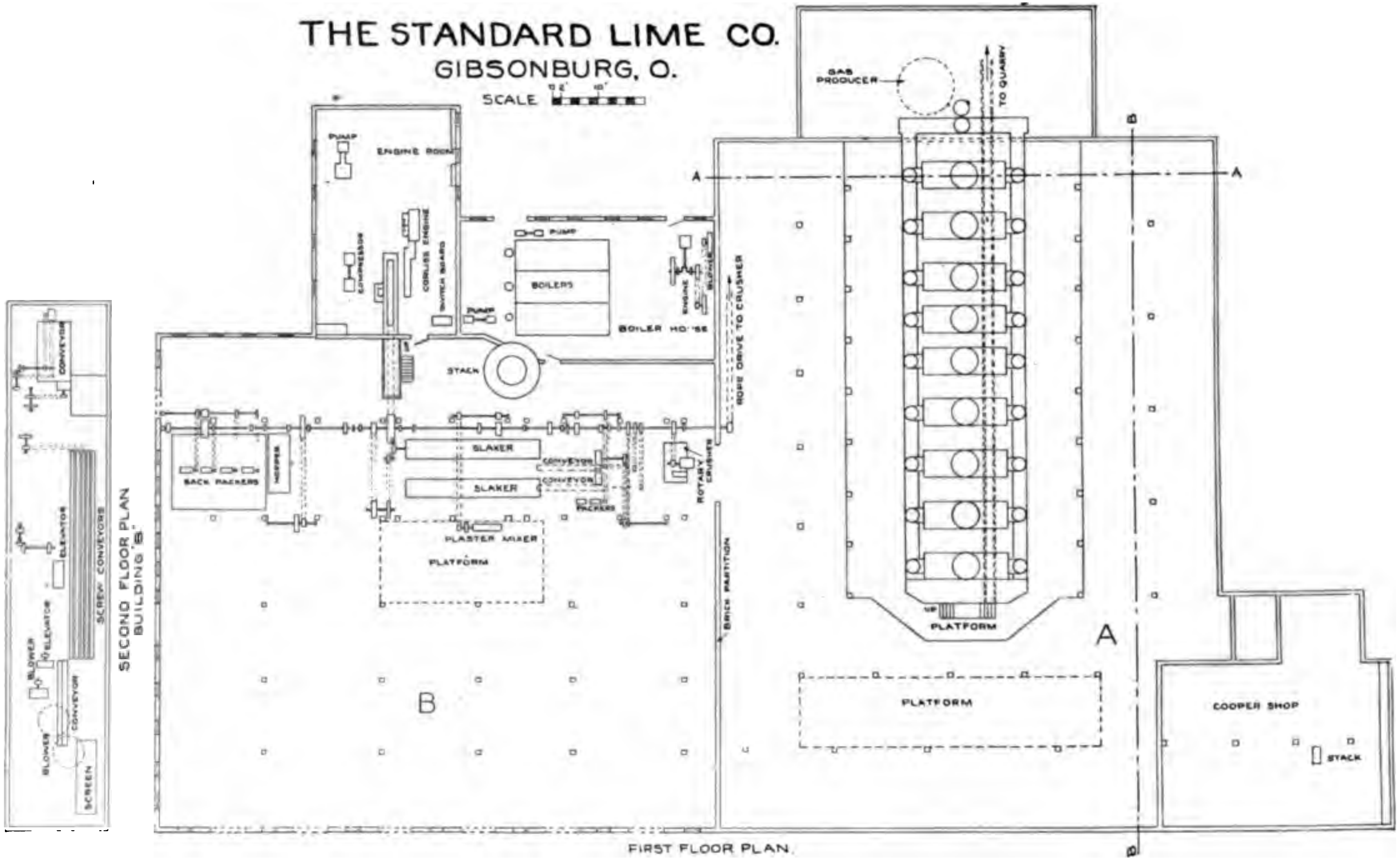
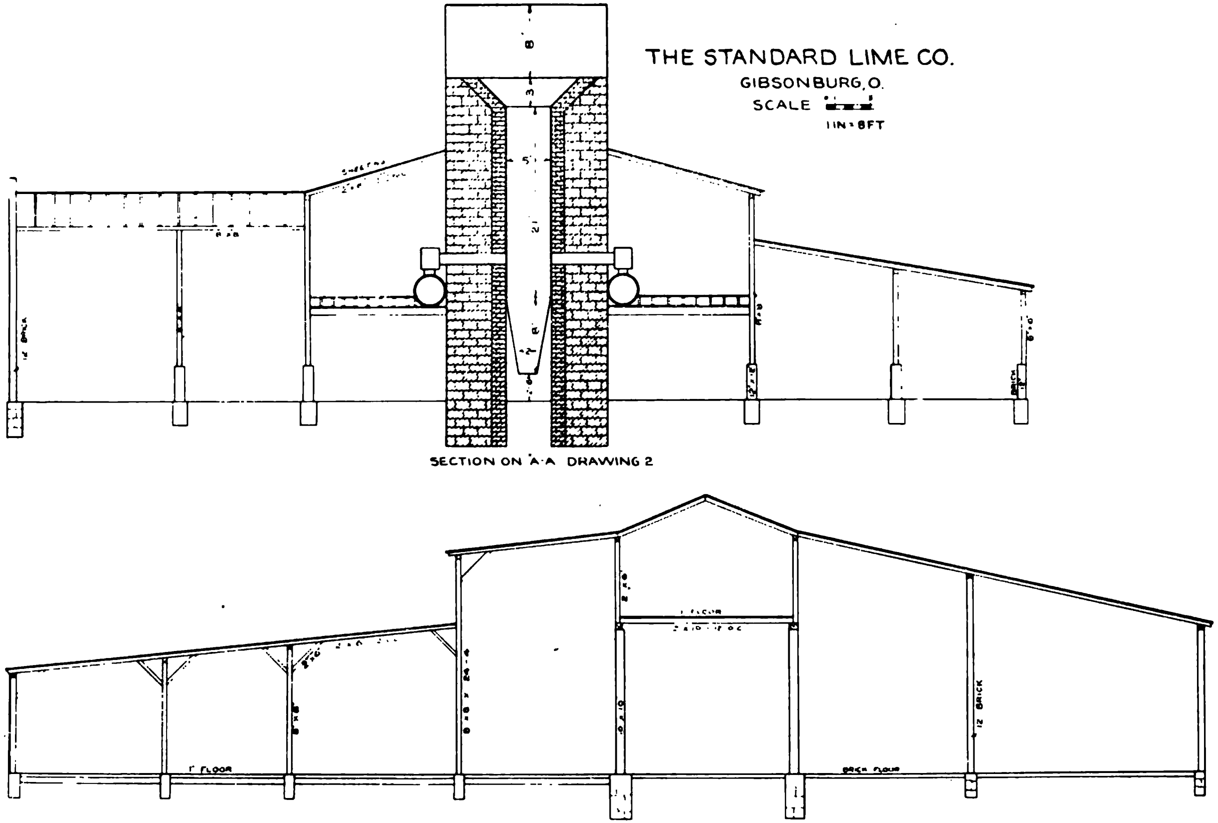


Figure 52.—First floor plan.



SECTION ON A-A DRAWING 2

SECTION ON B-B DRAWING 2

Figure 53.—Section of building and kiln.

BULLETIN No. 5.

THE MANUFACTURE

OF

ARTIFICIAL SAND STONE

OR

SAND-LIME BRICK

BY

SAMUEL VERNON PEPPEL, B. SC.

Springfield, Ohio.
The Springfield Publishing Company,
State Printers.
1905.

LETTER OF TRANSMITTAL.

PROFESSOR EDWARD ORTON, Jr. State Geologist:

DEAR SIR:—

I take pleasure in handing you herewith my work on the Sand-Lime Brick Industry. It is an attempt to place clearly before the public the fundamental principles of an industry which is yet but little known here, but whose products are knocking energetically for admission into the accepted lists of approved building materials I wish to thank you for the opportunity to study this interesting subject and for the opportunity to place the results of my study before the public. I also thank you for your kind co-operation and helpful advice given at all stages of my work.

Respectfully submitted,
SAMUEL V. PEPPEL.

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PREFACE BY THE STATE GEOLOGIST.

The manufacture of bricks and similar structural materials from sand bound together with some cementing substance has at all times been an attractive idea to builders. A number of different cementing substances have been used and each one has been the basis of an enthusaistic campaign in behalf of the material thus produced. None of these various materials have yet won for themselves a great or permanent place among the materials of construction.

The latest of these methods differs from all which have preceded it, both in the general nature of the bond established and in the method of its production. It consists of a calcium hydro-silicate, produced by the action of high pressure steam on a mixture of caustic lime and sand. This process, though no longer new, is still practiced in but a small part of the civilized world. It is, therefore, still new in its introduction to many countries, and is still a recent thing in America, though its growth here has been exceedingly rapid during the past three years.

This process has attained in Germany, and to a less extent in surrounding European countries, a development far in excess of any previous method of sand brick manufacture. In fact, it has become a large industry, with plants numbering over the hundred. It has won favor among German engineers and architects, who are very conservative and particular, and buildings constructed from it have been exposed to the weather of northern Germany for a number of years without indications of failure.

In view of these facts, it seemed to myself and the technical staff of the Survey, that it would be a matter of interest and importance to the public of Ohio, and in fact of the whole United States, to have this new process of manufacture carefully and scientifically studied and the results made known. This step was considered especially necessary, because in the last few years a number of companies have been formed for the purpose of promoting this process and inducing capitalists to embark in the manufacture of the new sand brick. The results in some of the early factories were not altogether successful, and the effect of these early failures and the too vigorous and perhaps indiscreet attempts to "boom" the sale of territory rights on some detail of the process by companies formed to promote the industry, have combined to create in the public mind a widespread distrust.

This distrust has been fostered also by the manufacturers of ordinary clay building brick, who think they perceive in this new material a dangerous competitor for their present product. The "greatest good to the greatest number" is of course the only rule by which such great economic problems can be settled, and neither the opposition of one class nor the equally objectionable "booming" of the other can ultimately determine the future of sand brick.

It was thought, however, that an ex parte investigation of the process and its product would hasten the day when a sane and rational view of the invention could become general, and it was undertaken with this object in view

Accordingly, Mr. S. V. Peppel, B. Sc., was detailed to investigate and report upon the industry. His opportunities to study it were quite complete. First, by travel and correspondence he has acquainted himself with the exact status of the various plants which have so far been erected in this country. Secondly. he has been provided with a miniature plant for experimental work in the various laboratories of the Ohio State University, and has been able to verify the statements and practices which he has met outside and to find out what is necessary and advantageous and what is immaterial or unfavorable in present practice.

These investigations were undertaken in June, 1901 and were completed in June, 1903, though much other work was carried on during the same period. They have been carried on in a spirit of pure investigation, and with the sole view of making the truth known, and it is hoped that the report will do much toward bringing this new industry into favorable notice, especially in such parts of the country as are well situated with regard to mineral supplies and other conditions.

EDWARD ORTON, JR.,
July, 1903. State Geologist.

ADDENDUM.

This report, having been delayed far beyond the usual limits before printing, is now in a measure out of date. The discrepancies arising are chiefly those that relate to the newness or rarity of the industry in this country. During the two years or so since this report was completed, many sand lime brick plants have been established over a wide extent of country. I am informed that not less than one hundred such plants have been completed.

This is, of course, entitled to some weight as evidence of the solidity and permanent value of this process of manufacture, but after all it is not convincing proof. Many fads have run their course in the commercial world just as they do in other departments of life, and mere adoption by large numbers is not proof of enduring value.

Of much more importance is the testimony of the business success of those plants which have been longest built, or which have been established long enough to get through their experimental stage, so that they know their materials, their processes and their product. Evidence of this sort is not equally abundant. Many plants which have been established have not yet reached a solid foundation. There is evidence that some plants now have material in buildings which have stood three years' test with satisfactory results. There are many rumors of contrary conditions prevailing elsewhere.

The industry has not grown in the simple, sound, but slow way which seems most desirable. One successful plant begets others. But "promoted" industries, which are strewn broadcast wherever a good salesman can land an order, are not often stable or successful, especially when they are dependent upon a chemical process.

That the sand lime brick industry can be made successful, whenever it is carefully and conservatively managed, by men of chemical training who devote the same care and technical control to it that is given to other chemical industries, admits of little doubt. That it can often succeed without these conditions or in the crude way in which it has been tried in many places, seems most doubtful. Its future depends chiefly on the use of trained technical men, rather than on promoters. If the same amount of brain, energy and good judgment is expended on this industry as has been expended on successful plants in other industries, we see no reason why it should not meet with the same measure of success.

Edward Orton, Jr.,
State Geologist.

PREFACE BY THE AUTHOR.

LOUISVILLE, KY., January 2, 1905.

In presenting this little volume to the public, I desire to thank the various firms manufacturing sand lime brick, as well as the firms who are building plants, for their courtesy in giving me access to their plants and for the frank answers given to my questions, as well as for their zeal in pointing out the problems with which they have had to contend, and in many cases the method by which they have been overcome.

I wish also to thank all those who assisted me in the experimental work recorded in this report, and especially Mr. Ervin Bailey, M. E., who was most helpful in making the mechanical tests of the finished material.

It should be borne in mind by the reader that while this report appears under date of 1905, it is a statement only of conditions up to the spring of 1903.

It may be said however, that up to the present time nothing has made its appearance either of a scientific or practical nature which has not been in support of what is herein set forth.

The growth of the industry has continued at a rapid rate. The more substantially built plants which have been in the hands of a capable management for a year or more have earned a good dividend for their owners.

SAMUEL V. PEPPEL.

THE MANUFACTURE OF ARTIFICAL SAND STONE OR SAND-LIME BRICK.

INTRODUCTION.

It was due to a realization of the importance of this new and rapidly growing industry, both to lime producers, to architects and builders, and to the general public, that the following study of this subject was made. The fact that there was a year ago some uncertainty as to whether sand brick was a safe building material, made an immediate examination on this point urgent.

The work was taken up primarily with a view of determining the properties and qualities of sand brick, and secondarily to determine the limiting conditions for the manufacture of a safe and durable product.

If sand brick are safe and reliable, it is due the public to know it; if they are unfit for general use, or unfit for specific uses, it is all the more important that the facts should be published. In any industry, and especially in a young one, there are always many questions, both as to the selection of raw materials and machinery for manufacture, which are the occasion of a great deal of uncertainty. When an industry is once well started, we know that with certain raw material, handled in a definite manner, in a certain machine or combination of machinery, certain desirable results can be accomplished. We also know that a certain raw material, exactly like in every respect to that in successful use, cannot always be had elsewhere. Or there may be something else, of little value for any other purpose, which could be just as well used and occasionally with a better result. And it generally happens that the first machines in use are not the most economical, or do not produce the best possible product. To determine the effect of impurities in the raw materials, and the requirements or demands to be made on the machinery used in the industry, was of prime importance to the work in hand. To do this, it was necessary to establish a small artificial sand brick factory, so constructed that we could modify and accurately control all working conditions.

This was accomplished by the aid of apparatus and machinery available in the various laboratories of the Ohio State University, supplemented by some special apparatus built for the occasion. The Department of Ceramics furnished grinding and mixing machinery. The Mechanical Engineering Department furnished a Tinius Olsen 100,000-pound testing machine which was used as a brick press. Cast iron molds and dies were made to order for this press. Our hardening kettle consisted of a wrought iron cylinder 10 inches in diameter and 7 feet long with union flanges on either end, onto which were bolted cast iron heads. The power and steam pressure were furnished from the University power plant.

CHAPTER I.

HISTORY AND DESCRIPTION OF THE INDUSTRY.

It is a long-known fact that a moist mixture of slaked lime and sand becomes hard on being exposed to air, a process which depends upon the absorption of carbon dioxide. For many years blocks or bricks have been manufactured, depending on this reaction, by simply molding a sand and slaked lime mixture and exposing it to air. These bricks were known as lime sand brick, but *mortar brick* would probably have been a better term for all blocks in which the sand mass is held together by a calcium carbonate filler, while the term *sand brick* might be applied to all bricks which have a calcium or calcium-magnesium silicate bond, the combination between the sand and lime being brought about by the influence of steam.

Sand brick or the "Kalksandstein" of the Germans is a mass of sand particles bound together by either calcium carbonate or calcium hydrosilicate, or a mixture of both.

Mortar brick, with calcium carbonate as the cementing material, have been manufactured for fifty years or more. The manufacture of sand brick with calcium silicate as the cementing and filling material between the grains of sand does not date back more than ten or twenty years. In the latter a chemical combination or reaction between the two constituents of the brick, slaked lime and sand, takes place, which binds the two materials together in a manner akin to vitrification. The resultant product is similar in many respects to dry pressed bricks in that the bonding extends only to the surface of the sand grains.

For either the mortar or the sand brick the raw materials are the same, sand or a granular silicate and slaked lime, either a high calcium or a magnesian lime. The method of treatment during the process of manufacture differentiates them into three distinct products, all of which are known indiscriminately as sand bricks.

Sand bricks with a lime silicate bond are the only ones known in this country, and are the only ones deserving extended study. However, we will also consider briefly the other products. Mortar brick may be produced by three distinct methods.

SAND BRICK WITH EXCLUSIVELY CARBONATE FILLER.

It is obvious that the stone which has carbonate of calcium as a filler or binding material cannot have the same strength as the one in which there is a chemical union of the sand and the calcium or magnesium compound, as the case may be.

Twenty to forty per cent. of completely slaked lime is thoroughly mixed with sand and sufficient water to make molding possible at moderate pressures. The hardening process is carried out in one of three ways:

First. The brick are exposed to the action of the atmosphere for a long time, the caustic lime thus slowly acquiring the needed carbon dioxide ($CaO + CO_2 = CaCO_3$). The necessity for complete slaking is evident, since any unslaked lime would slake in the air and rupture the brick. The time required before they can be used is five to six months, and they attain their maximum strength in about one and one-half years. The hardening here is similar to that of mortar, and like mortar is only superficial. The best lime for this purpose would naturally be a hydraulic lime, since the hydraulic properties of the lime would add strength to the mixture aside from that due to the formation of calcium carbonate. Zwick has said that only thirty per cent. of the lime in very old mortars had been converted into the carbonate.

Second. Hardening in an atmosphere rich in (CO_2) carbon dioxide, such as the gases from a lime kiln or a combustion furnace of any sort, without pressure. This gives the same results as the first process, in less time.

Third. Hardening with (CO_2) carbon dioxide under pressure. It is claimed by some that this means gives a product in which nearly, if not all the calcium hydroxide $Ca(OH)_2$ is converted into carbonate. However, the writer does not believe that this has been satisfactorily proven, and he is of the opinion that the carbon dioxide will form a carbonate of lime on the surface, closing the pores of the brick, and thus preventing the entrance of sufficient carbon dioxide into the body of the brick to make the conversion to the carbonate complete.

SAND BRICK WITH PARTLY CARBONATE AND PARTLY SILICATE FILLER.

In this process the treatment up to the hardening process is essentially the same as just described, but the hardening is effected in a warm, moist atmosphere, saturated with CO_2 from lime kilns, or other sources. The heat of slaking lime is sometimes used to aid in keeping the temperature up to 60-70 degrees C. A combination of these methods provides for the introduction of CO_2 into kettles or closed iron cylinders used for steam hardening. Under the conditions first cited, the product has as a binding material for the most part $CaCO_3$, but some hydrated calcium silicate is probably formed, thus strengthening the bond. In the latter the binding material is mainly the calcium hydrosilicate, and the amount of calcium carbonate much less than the former.

I am inclined to the belief that here also the superficial hardening prevents anything like a nearly complete change of the $Ca(OH)_2$ in the center of the stone. This, of course, would be no detriment to this product, or the preceding one, except to give a weaker brick, provided only that the surface had reached sufficient hardness and density to prevent all access of water or gases. If this is not obtained, we should expect efflorescence as a result of the solubility of the calcium hydrate.

SAND BRICK WITH HYDROSILICATE FILLER.

This brings us to the third class, the only one which I think will ever take any important place in the world's markets. For this reason we shall go into the essential facts more closely.

The same raw materials are used as in the other processes, viz: sand and lime.

PROCESS OF MANUFACTURE PRIOR TO HARDENING.

In present practice, one of four methods prior to hardening are employed, the differentating features being the mode of preparing the lime:

1. The wet slaking process.
2. The dry slaking process.
3. The acid slaking process.
4. The quicklime process.

Wet Slaking Process.—This process consists in slaking the lime to a fat putty, either by hand or by mechanical aids, and then mixing in the desired proportion of sand and water in a wet pan or a pug mill. From here it is carried to bins over the press, allowed to stand a short time, and then pressed.

With properly burnt fat, or high calcium lime, the addition of the proper amount of water and with sufficient agitation and labor, this can be accomplished. The heat given up by the union of caustic lime and water is sufficient to generate steam in the minute pores of the amorphous oxide and thus break it up into the smallest possible particles, constantly and rapidly exposing new and fresh surfaces to the hot water. Calcium oxide on hydration gives up 246 calories per gram. Under these conditions the CaO seems to form a hydrate carrying more than one molecule of water, the excess being locked in so loosely that a little excess of heat, as would be the case with too little water, would prevent its formation, or break it up, if formed. If there is not sufficient water the lime will become too hot, if there is excess the temperature will be too low for the best results. The product of correct slaking is an extremely tough and plastic mass.

Walters found that the best slaking of high calcium lime gave an increase of 3½ times the original volume, air slaking 2½ and slaking with a large quantity of water 1.7. This increase in volume gives it greater spreading or enveloping power.

With the dolomites more time is required for proper slaking, for two reasons:

1. The magnesium oxide is somewhat overburned at the temperature of complete expulsion of carbon dioxide from limestone and hence is above its point of maximum porosity.

2. The heat evolved by magnesium oxide on hydration is much less than that for the hydration of calcium oxide. Both act in the direction of retardation. Pure dolomite lime yields about 130 calories per gram.

The process of hydration for this type of lime can be much improved and hastened by the use of hot water or the application of external heat. It is claimed by many that the magnesian limes never develop the same degree of plasticity as the fat limes. This may in part be due to imperfect slaking.

When lime of any sort is prepared in this manner and used in the form of putty, its even incorporation into the sand is very difficult to attain, owing to the plastic, sticky nature of the lime paste. Little balls form, consisting of a nucleus of lime surrounded by a mass of sand particles, which prevents the further distribution of the lime over the surface of the sand grains, except by the most vigorous rubbing.

When a complete and even distribution of the lime is obtained, the mixture works well in the press and will make a good brick.

If this process is used it will be found advantageous to work the paste up into a cream with water before the sand is added. This thinning down of the lime greatly facilitates its distribution.

The Dry Slaking Process.—This differs from the preceding only in the fact that the lime is slaked with just enough water so that the heat of the chemical reaction will dry the finished hydrate. The hydration is incomplete in most cases. There are a number of patented processes and patented machines on the market for doing this, both in this country and in Europe. Some of the devices are closed tight, and the slaking is done under pressure with water alone; in others the lime is treated with both water and steam.

In another type, water is added to the lime in a partially closed vessel, and heat applied externally by means of a steam jacket.

H. E. Brown claims that dolomite lime hydrated under the conditions last mentioned in a steam jacketed machine, showed on chemical analysis complete hydration, with a three-fold increase in volume, and yet is a dry product.

The experience of the writer did not confirm the above statement. On slaking with steam alone about two and one-half volumes for high calcium lime and about two volumes for dolomite lime were obtained.

In none of the various methods tried for slaking did the increase in volume of dolomite lime exceed that of the high calcium lime under similar treatment.

In every case where hydrated lime, prepared by any of the dry slaking processes now in use, was examined, a lack of combined water was found—that is, slaking was incomplete. The deficiency in water varied in different samples from a few per cent. up to ten per cent. of the weight of the lime, or in other words, there was only from 60 to 95 per cent. of the water present which should have been there. All of the samples examined were magnesian limes, and all were safely stored in paper sacks. It does not seem probable that a deficiency of ten per cent. of water in a dry slaked magnesian lime would be dangerous for mortar purposes or for the manufacture of sand lime brick.

For sand lime brick, a steam-slaked lime, whether hydration is complete or not, is safe, since it has expanded all it will under the action of steam.

Where magnesian lime is used in this industry, this is the method of preparation which should be used, since the dolomite limes slake too slowly to make the quicklime process available.

The fine state of division in which the lime hydrate is left after dry slaking gives it the best possible physical condition for uniform distribution and chemical reaction. The dry hydrate can be rapidly and completely incorporated into the sand, and when moisture is added later there is but little tendency to ball up. With wet sands the incorporation of the hydrate is not so easy, but it can be done with much greater facility than with the pasty lime hydrate.

Acid Slaking Method.—In this process 5 to 10 per cent. of a solution of common hydrochloric acid, 19° B., is added to the lime after slaking has begun. This is the basis of a German patent issued to P. Kleber. In the preliminary slaking the hydration is carried only to from one-third to one-fifth of completion, so that only one-third or one-fifth of the lime is converted into calcium chloride. This compound, as is well known, has a great affinity for water and is also very active in attacking silicates, as is illustrated by its action in the nascent condition made use of in the J. Lawrence Smith ignition for the determination of the alkalies.

The introduction of the acid must be objectionable at any rate since if the calcium chloride remains as such it would be soluble later and give trouble. If it is decomposed, and calcium silicate formed, the acid liberated in the atmosphere of steam must certainly attack the metal cylinders unless they are glazed with a silicate of some sort or lined with lead. The reaction involved in this process is:

$$CaCl_2 + SiO_2 + H_2O = CaSiO_3 + HCl.$$

It is claimed by Kleber that the acid accelerates the slaking and shortens the time needed in the hardening cylinder. The introduction of calcium chloride is claimed to be less satisfactory than the use of the acid. The cost of the latter may vary from 1 to 1½ cents per pound. While there are a number of plants operating under this patent, the writer does not believe that any acid is now used Kleber's American patent differs from his process patented in Germany and will be discussed later.

The Quick Lime Process.—In this the dry calcium oxide is mixed with the sand and just enough water is added to slake the lime and to put it into the proper condition for pressing. The water is usually added in two portions with a short interval of time between additions to give the lime time to absorb all of the water it can carry. The product then goes to the press, or to a silo for sweating. The silo method has for the most part been abandoned.

This certainly is the most rational and rapid method, where the available materials are such as can be successfully worked in this manner. There is no rehandling of any of the materials. The sand and lime start in together at one end of the plant and come out at the other a finished product without intermediate delay, except that involved in the steam treatment.

This method will require the use of at least two mixing machines and preferably three, and they should be so geared that the mixture does not reach the press under twenty minutes after the time water was added to the lime. If an intermittent mixing machine, such as the Schwarz mixing machine, is used, the mixture, in order to attain complete hydration and adequate distribution of the lime, must be kept in the machine sufficiently long.

This method is not adapted to the use of all kinds of limes. It requires a sensitive, quick slaking lime, and hence the only limes which should be used are the high calcium or hot limes, and these should not be overburned or exposed to the air any length of time after burning. The ideal way would be to burn the lime at the plant as needed, using it at once. This, however, would be feasible only with plants of large capacity.

A sand containing considerable moisture can be used without disadvantage, since the absorption of water by the quicklime will remove a considerable quantity of moisture from the sand and the heat generated by slaking will aid evaporation as well. If the plant is properly arranged the mixture will go through the press while still quite warm and into the hardening kettle before cold. In this manner some steam is saved in the hardening process, since not quite as much steam is condensed in raising the temperature of the brick up to the temperature of the steam. The amount of steam condensed will, of course, be the less the higher the initial temperature of the brick is.

MIXING.

Since the thoroughness of the mixing process is the key to the success of the process, almost every known mixing device has been tried. The predominating types of mixers in use today are the pug-mills and the tube-mills. The Schwarz mixer is also much used.

PRESSING.

Owing to the gritty character of the mixtures, and their very reluctant flow in the die under pressure, and the very rapid increase of the pressure after a certain percentage of reduction of volume has been reached, the demands on a machine to successfully make sand brick are different from those of any other process, and could not be furnished satisfactorily by any of the brick presses designed for making dry-press clay brick, until they had been strengthened for the new duty. After trials of all the various kinds of presses, the rotating table press predominates in European practice, while in America the honors are about evenly divided between the table press and the upright dry-press machines used for clay brick.

HARDENING PROCESS.

The hardening is accomplished in one of two ways, either by low pressure steam and long exposure, or high pressure steam and short exposure. In the first case, the pressure used is about two atmospheres, giving a temperature of about 125 degrees C, and the duration of the exposure is in the neighborhood of seventy-two hours; in the second case, the steam pressure is from seven to ten atmospheres, giving a temperature of 170 to 185 degrees C. and the exposure lasts for a few hours only, six to ten hours being sufficient in most cases. The latter procedure, using seven to ten atmospheres of steam pressure in hardening, is now almost universal in the industry.

There are probably more plants operating at a steam pressure of 115 to 125 pounds to the square inch than at any other. The above pressure gives temperatures around 175 degrees C. and the time needed is eight to ten hours after the brick have reached this temperature. It usually requires from forty-five to sixty minutes to raise the temperature of the hardening cylinder after it has been filled. This time is dependent, to some extent, on the steam-producing capacity of the plant, and the size of the inlet valve.

The letters patent on this most important procedure, hardening by steam under pressure, were taken out by Professor Michaelis early in the eighties, and permitted by him to lapse without commercial application. *This procedure is therefore public property and any one may use it without danger of suit for infringement.*

I have already mentioned a modification of the hardening process in which carbon dioxide is introduced either with the steam or after it. If this method is used at all, it is employed only when working with low-pressure steam.

CHAPTER II.

THE RAW MATERIALS, THEIR IMPURITIES, AND THEIR PREPARATION.

SAND.

1. Almost any sand can be used, and a fair product produced, if the treatment is properly varied to suit the physical and chemical properties of the sand. Economy in manufacture, however, limits both the physical and chemical properties of the sand, somewhat sharply. While a moderately strong brick of good appearance can be made from almost any sand, yet there are certain limitations in the chemical, or rather the mineralogical constitution of the sand, aside from those dictated by economy in manufacture, if we expect to obtain a thoroughly safe and durable material, as will be shown later by experimental results. A sand containing too much clay will make a brick which will not stand up long under the attacks of severe climates.

2. A comparatively pure sand is essential to cheap manufacture, as well as for the production of a safe and durable material, nor should the sand be too coarse. It is probable that for the best results most of it should pass through a screen 20 meshes to the inch, unless there is a good gradation from extremely fine to coarse sizes, in which case perhaps coarser sand could be worked in to advantage. The product would not be as smooth and pleasing to the eye as one made from finer sand.

The object is to obtain a sand which will contain enough very fine particles to combine with the lime, and which when pressed will leave the smallest possible interstitial spaces, thus reducing the amount of lime necessary for welding these particles together to the minimum.

Work done in connection with the cement industry has shown that practically none of the sand coarser than 100 mesh, and only a part of that of 150 mesh, enters into the active cement reaction.

As an illustration, suppose we had one sand all of the size of walnuts and another all of the size of wheat. Enough of the smaller could be mixed in to materially reduce the interstitial space, and yet leave sufficient space for a binding agent.

The finer the material, as a whole, the more difficult will it be to so mix it as to get a coating or film over each particle of sand. On the other hand, the union will be more complete, and the product more pleasing to the eye.

Experiments carried out by Prof. M. Gasenapp in the chemical technical laboratory of the Polytechnic Institute at Riga, the results of which were published in the Thonindustrie Zeitung for October, 1900, p. 1703, and Vol. 25, p. 762, clearly show the necessity of using fine sand for rapid and economic production.

A set of results were first obtained with fat or high calcium lime as the active agent, and a second with lean or dolomite lime.

In both cases a very pure, sharp, coarse sand 0.6 to 1.0 mm. in diameter was used, and a fine sand, 0.2 to 0.3 mm. in diameter. The fine sand was somewhat rounded and contained a considerable quantity of soluble silicic acid, therefore it was treated with HCl, and caustic soda solution, and washed before using in the experiments.

Each size of sand was treated with 10 per cent. and 20 per cent. of lime, respectively, and with 10 and 20 per cent. of dolomite lime. High pressure steam was used. Both sets were run for eight hours, one at 5 atmospheres pressure, the other at 10 atmospheres.

The analyses of the resultant products given below in Tables I and II are self-explanatory. The soluble silicic acid is an index to the extent of the reaction. The methods of analysis are not given. The samples were exposed to the air for from two to five weeks, which probably accounts for most of the carbon dioxide, since the $Ca(OH)_2$ was not all converted into the silicate.

TABLE I.

Series A. Briquettes in which pure lime was used. Analyzed after eight hours' exposure in steam cylinder.

Number.	Mixture.	Steam pressure in atmosphere.	Total CaO	Ca(OH)$_2$ from total.	MgO	Al$_2$O$_3$+Fe$_2$O$_3$	CO$_2$	Chemically combined water.	Soluble SiO$_2$	Sand.	Total.
1	90 parts coarse sand......... 10 parts lime...............	5	6.50	1.67	......	......	3.45	0.88	0.43	89.10	100.37
2	Same as No. 1.	10	9.38	1.24	......	0.42	2.54	2.96	3.33	82.00	100.63
3	80 parts coarse sand......... 20 parts lime...............	5	16.69	7.16	......	......	4.77	2.78	0.59	74.67	99.50
4	Same as No. 3.............	10	16.59	6.05	......	0.29	3.02	4.60	2.75	72.85	100.10
5	90 parts fine sand .... 10 parts lime...............	5	8.74	0.85	......	0.31	3.75	1.79	3.06	82.02	99.67
6	Same as No. 5.............	10	10.10	0.58	......	0.56	2.23	2.55	7.58	76.88	99.40
7	80 parts fine sand........... 20 parts lime...............	5	15.81	4.23	......	0.31	5.21	3.90	3.41	70.68	99.32
8	Same as No. 7.............	10	17.67	0.98	......	0.65	3.13	3.59	11.14	63.05	99.42

TABLE II.

Series B. Briquettes in which dolomite lime was used. Analyzed after eight hours' exposure in steam cylinder.

1	90 parts coarse sand......... 10 parts dolomite...........	5	4.98	0.38	3.81	0.23	2.21	2.24	0.75	85.23	99.45
2	Same as No. 1.............	10	4.49	0.43	3.45	0.96	2.05	2.13	3.14	83.61	99.83
3	80 parts coarse sand......... 20 parts dolomite...........	5	8.56	2.53	6.58	0.70	3.38	3.44	0.65	75.80	99.11
4	Same as No. 3.............	10	9.97	1.92	7.57	0.95	3.19	4.39	1.69	72.62	100.18
5	90 parts fine sand........... 10 parts dolomite...........	5	4.97	0.92	3.75	0.68	2.22	1.82	1.98	84.23	99.65
6	Same as No. 5.............	10	5.40	0.40	4.07	0.95	1.92	1.88	6.29	79.28	99.79
7	80 parts fine sand........... 10 parts dolomite...........	10	9.23	0.79	7.00	0.94	1.82	5.74	7.03	67.88	99.64

Influence of Fineness.—Considering the above tables, I and II, we see that the coarse and fine sands were very differently affected under the same conditions. This is brought out more clearly by Table III, which is a condensation of I and II to illustrate this point:

TABLE III.

Percentage of caustic filler used.	Pressure of steam in atmospheres.	Percentage of soluble silica found by analysis of Product.		
		Kind of caustic filler used.	Using coarse sand.	Using fine sand.
10	5	Pure Lime	0.43	3.06
		Dolomite Lime	0.75	1.98
	10	Pure Lime	3.33	7.58
		Dolomite Lime	3.14	6.29
20	5	Pure Lime	0.59	3.41
		Dolomite Lime	0.65	....
	10	Pure Lime	2.75	11.14
		Dolomite Lime.	1.69	7.03

In every case the reaction is much more complete with the fine sand. This shows clearly the necessity for some fine quartz. The reaction has gone a great deal farther with the fine than the coarse, although the fine sand was not in as favorable physical shape for chemical union as the coarse. If soluble silicic acid were naturally in the sand, it might take the place of fine sand. In each case, the lime was not all combined with silica; that is, the reaction was incomplete, as is shown by the presence of uncombined calcium hydrate. After deducting from the chemically combined water that which would go with the calcium hydrate, the balance of the water gives some striking molecular ratios to the soluble silicic acid. Thus from Table I and II we have

TABLE IV.

Series A.

Number................	1	2	3	4	5	6	7	8
Ratio..................	3.7	2.66	6.50	3.7	1.7	1.	2.8	1.

Series B.

Number................	1	2	3	4	5	6	7	.....
Ratio..................	9.55	2.16	14.4	7.4	2.7	0.93	2.60	.....

The ratios 6.5, 7.4, 9.55, and 14.4 seem a little unusual to me. It is notable, however, that, with one exception, the high ratios are with the MgO.

These results also show clearly that high steam pressure in hardening is essential to anything like rapid working.

Professor Michaelis is quoted as saying the higher the pressure, the higher the amount of soluble silicic acid, and the more solid and denser the resulting brick.

Professor Michaelis has given the physical properties of the sand primary importance, and chemical properties a secondary place. He also says that two-thirds coarse and one-third fine sand gives a denser and firmer brick than where the sand is all one size. Seventy per cent. coarse sand, 30 per cent. fine sand, with 5 per cent. lime gives a good product, having 7 to 8 per cent. porosity. He has also shown that good brick can be made with sand carrying as much as 40 per cent. clay, if sufficient lime is used.

He does not, however, present any evidence to show that the brick containing so much clay did not fail under the action of severe freezing.

Judging from his figures, the writer thinks that for each part of clay present a little less than one part of lime must be added in excess of that which would be needed for the sand itself.

The effect of clay will be considered under the head of impurities in the sand.

Proportion of Coarse and Fine Sand.—Returning to pure sand, from the work quoted above, it is evident that there should be some very fine sand present. The next question must be: What proportion of fine material is desirable?

The statement of Dr. Michaelis, that two-thirds of coarse and one-third of fine sand is best, is a little indefinite, since coarse and fine are not in any way defined. It is reasonable to suppose that the mixture which will leave the smallest amount of interstitial space when pressed together will be the strongest. This might be calculated exactly. But since it would not be attainable in a commercial way, the calculation is omitted and practical tests will be given to show the effect of varying the amount of very fine sand.

In all this work a pure, sharp glass sand was used as the coarse element, the mechanical analysis of which gave the following results:

	Per cents.
Retained on 20 mesh sieve	0.0
Retained on 40 mesh sieve	50.0
Retained on 60 mesh sieve	33.0
Retained on 80 mesh sieve	7.0
Retained on 100 mesh sieve	7.0
Retained on 120 mesh sieve	2.0
Retained on 150 mesh sieve	1.0

The fine sand was introduced in the shape of a pure potter's flint, the mechanical analysis of which showed the following results:

	Per cents.
Residue on 120 mesh sieve	0.70
Residue on 150 mesh sieve	1.00
Residue on 200 mesh sieve	1.25
Grains of average diameter 0.0212 inch	24.00
Grains of average diameter 0.0086 inch	19.00
Grains of average diameter 0.0004 inch	8.50
Grains of average diameter 0.00026 inch	7.50
Grains of average diameter 0.000136 inch	5.70
Grains finer than the last size	32.35

Both sands were practically free from soluble silica.

Different mixtures representing several ratios of coarse to fine sand were now made, and to each 5 per cent. of calcium hydrate and 5 per cent. of water above that needed for hydration was added. The lime was steam slaked. All other conditions of making the sand lime briquettes were kept as uniform as possible. The results, each representing the average of three tests, are given in the following table;

TABLE V.

Number.	Ratio of coarse to fine grains.	Crushing strength pounds per square inch.	Tensile strength pounds per square inch.
77	8 coarse: 2 fine	3114	131
79	4 coarse: 2 fine	2955	144
84	3 coarse: 2 fine	2461	224

These results indicate clearly that the ratio of coarse to fine grains is extremely important and also that much more work is necessary in determining the best ratio. It is quite evident from the above figures that a decrease in the proportion of coarse sand decreases the crushing strength while the tensile strength is increased.

While this is the case for the range of mixtures examined, when carried further, limits will be reached in both directions, and the writer regrets that he is unable at present to fix these limits.

The blocks for the preceding tests were made in a hand screw brick press,on which it was impossible to give each block exactly the same pressure. Since, as we shall show later, the pressure has a decided influence on the strength, the above results would probably show a closer relation between the decrease in crushing strength and increase in tensile strength with the increase in the amount of very fine particles present, if they had been made in a machine where this pressure was under accurate control.

From the foregoing it may be concluded that for the best working conditions in using a sand all of which is retained on a 40-mesh sieve, we should pulverize one-fourth of the sand so that at least one-half of this amount (one-eighth of the whole) passes the 150-mesh sieve. However, if we had sand with a good assortment of sizes from coarse to fine, the amount of fine sand passing the 150-mesh sieve should be at least equal to the lime to be added.

The fine sand not only fills the spaces between the coarse particles, but assists in the even distribution of the lime and very much accelerates the chemical reaction so necessary to strength.

Effect of Shape of Grain.—While it is very probable, indeed, that sharp sands are much to be preferred, no comparative tests to show just to what extent the shape of the grains will affect the strength of the material produced have been made.

ORDINARY IMPURITIES.

Clay Substance.—The ordinary impurities in sand are for the most part silicates represented by clay or kaolin, mica and feldspar, and almost always some ferric oxide. While mica and feldspar are frequently absent, clay and oxide of iron are scarcely ever lacking entirely. While usually feldspar and mica are not present in important quantities, there are regions in which the sands are rich in one or the other, and sometimes in both. Oxide of iron, which is nearly always present in greater or smaller quantities, reacts with silica very feebly, if at all, in the presence of steam under pressure, and may therefore be considered inert except for its coloring action. It may, however, act as a promoter of chemical combination analogous to the action of ferric oxide in Portland cement. No attempt was made to determine whether this is the case or not. By far the most common impurity found in sand is clay. If there is any impurity in a sand at all, it is usually clay. Its effect on sand brick was, therefore, studied more in detail than that of any other impurity.

No bricks were made with sand carrying mica, since ordinarily it would not be found in sufficient quantity to do much damage.

Professor Rinne, of Hanover, commenting on the examination of a number of thin sections of sand lime brick under the microscope, says:* "Mica flakes do not seem to have been materially attacked. Quartz and feldspar do not show much, if any difference." That is the quartz and feldspar unite with the lime in about equal proportions.

From theoretical considerations we might say that the presence of silicates in any large quantity would act as a dilutant or inert material, with perhaps a few exceptions. Kaolin (Al_2O_3, $2SiO_2$, $2H_2O$) may be converted into anorthite (CaO, Al_2O_3, $2SiO_2$), but we do not know this to be the case. Also anorthite, if present in the sand, might take on four molecules more of SiO_2 and five molecules of H_2O as water of hydration

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***Tonindustrie Zeitung*, 1903, No. 16, p. 193.

and form heulanite ($5H_2O$, CaO, Al_2O_3, $6SiO_2$), and the acid ortho-silicates represented by phenite (H_2O, $2CaO$, Al_2O_3, $3SiO_2$) might take on another molecule of CaO and give up a molecule of H_2O.

It is hardly likely that the normal silicates would become more basic in the presence of large quantities of available silicic acid. It is not likely that the metasilicates, represented by the simplest silicates of calcium and magnesium, Enstatite (MgO, SiO_2) and Wollastonite (CaO, SiO_2), can do more than promote the crystallization of the calcium or magnesium silicates formed by their mere presence in crystalline form.

Since the base of all clays is kaolinite the action of this mineral as representing the hydrous silicates was examined and that of feldspar as representing the more complex anhydrous silicates.

For kaolin the following mixtures were made up into cubes and briquettes, using 5% of the same lime in each case for the mixture of tables VI and VII, but in table VIII 5% of a different lime was used.

In tables VI and VIII the ratio of coarse particles to fine particles in the sand mix was 4 to 1 and in table VII 3 to 2, in IX, 2 to 1 and 10% high-calcium lime; in X, 2 to 1 and 10% dolomite lime. Hence the tables are not comparable with each other. However, in each table the only variable in the mixtures used is the amount of kaolin which was used to replace the flint or fine materials. Tables IX and X are the averages of a comparatively large number of tests.

Data:—
Steam Pressure—150 pounds per square inch.
Temperature in Hardening Cylinder—185° C.
Time Exposed to Steam—10 hours.

TABLE VI.

Molding Pressure—10,000 pounds per square inch.

Number of test.	Composition of mixtures.					When tested.						Water absorption in per cents of dryweight of brick.
	Parts coarse sand.	Parts fine sand (including impurities).	Per cents kaolin.	Per cent. quicklime.		At once after hardening.		After aging.		After freezing.		
				Pure CaO.	Dolomitic.	Crushing strength.	Tensile strength.	Crushing strengsh.	Tensile strength.	Crushing strength.	Tensile strength.	
85	4	1	2.5	....	5	2766	338	2449	194	2917	219	8.32
86	4	1	5.0	....	5	2500	210	2376	277	2481	181	8.00
87	4	1	10.0	....	5	1943	184	1687	157	1910	121	8.50
88	4	1	20.0	....	5	1705	162	1325	138	1477	93	9.00

TABLE VII.

Molding Pressure—10,000 pounds per square inch.

83	3	2	. .	. .	5	3697	427	....	...	3812	215	8.06
89	3	. .	2	. .	5	2260	238	1846	187	2117	156	10.36

TABLE VIII

Molding Pressure—10,000 pounds per square inch.

Number of test	[illegible]	[illegible]	Per cent. kaolin	Per cent. moisture [illegible]	[illegible]	[illegible] after hardening [illegible]		After aging [illegible]		After freezing [illegible]		Per cent. water absorption
						[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

TABLE IX

Molding Pressure—15,000 pounds per square inch.

[illegible]*	[illegible]	[illegible]		[illegible]		[illegible]	[illegible]			[illegible]	[illegible]	[illegible]
[illegible]†	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]			[illegible]	[illegible]	[illegible]

*[illegible] the average of tests Number [illegible] and [illegible]

†[illegible] the average of tests Number [illegible] and [illegible]

TABLE X

Molding Pressure—15,000 pounds per square inch.

[illegible]*	[illegible]	[illegible]		[illegible]		[illegible]	[illegible]			[illegible]	[illegible]	[illegible]
[illegible]†	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]			[illegible]	[illegible]	[illegible]

*[illegible] the average of tests Number [illegible] and [illegible]

†[illegible] the average of tests Number [illegible] and [illegible]

TABLE XI*

Molding Pressure—[illegible] pounds per square inch.

[illegible]	[illegible]		[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]		[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]			[illegible]	[illegible]	[illegible]			[illegible]		
[illegible]	[illegible]	[illegible]			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	

*[illegible]

Conclusions on the Effect of Clay.—Reviewing the facts expressed in tables [illegible] and [illegible] where the bricks were made under a pressure of [illegible] pounds to the square inch we observe that [illegible] [illegible] of kaolin there was a marked [illegible] in both crushing and tensile strength. This was most marked in table [illegible] where the proportion of [illegible] was large [illegible] coarse [illegible] No. [illegible] and in No. [illegible] where [illegible] of this was replaced by kaolin. The [illegible] in crushing strength [illegible] [illegible] per cent. of kaolin was at least [illegible]

Tables IX and X the bricks for which were made under a pressure of [illegible] pounds per square inch [illegible] a different story. Here again with the addition of kaolin there is a marked falling off in crushing strength, but in this latter case it is accompanied by a very decided increase in tensile strength. The effect of the pressure used in molding the block will be discussed under the topic of pressing.

Coming back to tables VI and VII, we observe that No. 88, with 20% kaolin, shows a very decided loss in strength after the freezing test as well as after aging for 35 to 40 days. This is also the case with No. 89, which likewise is very rich in kaolin.

The increase in strength shown here after freezing will be discussed later in connection with the effect of freezing in general, on all kinds of sand lime bricks made.

It was next thought that an increase of lime might overcome the ill effects of a large amount of kaolin and to test this point No. 92 was prepared and made under the same conditions as No. 89, excepting that 20% of lime was added instead of 5%. This proved that an increase of lime did in a measure counteract the action of high kaolin. On comparing the figures of table XI, it will be noted that between 89 and 92 there is a marked increase in strength, the tensile strength being more than doubled and that after the freezing test No. 92 shows an increase in crushing strength while No. 89 shows a decrease. However, going further and comparing No. 83 with 90, which has no kaolin and in which the lime was only increased from 5 to 10% ,we see that there is approximately as much increase in strength for the addition of 10% of lime as there was with 20% in the preceding case where kaolin was a large part of the mixture. Another very pertinent point to be observed is that the increase in strength after freezing is very much greater in the case Nos. of 83 and 90 than it is with Nos. 89 and 92.

Thus while an increase of lime does in a measure overcome the bad effect of a large amount of clay, we are safe in saying that any considerable amount of clay in a sand to be used in this industry is very undesirable, since to use enough lime to make it a safe product would be too expensive, and after all the product would not be the best in quality.

From the preceding facts it would appear that clay up to 10 or 12% is probably not injurious, and possibly as small an amount as 2.5% might be desirable.

Clay adds to the ease of molding since owing to its smooth, unctuous nature it acts as a lubricant and decreases the friction in the mold.

The Effect of Feldspar.—The effect of feldspar was not examined in the same detailed manner that kaolin was, since it is not so common an ingredient in quantity. However, a number of blocks having 10% of feldspar in the sand were made under a presure of 15,000 pounds to the square inch. Only the average results of all the tests on these experiments are given under F in table XII, which also contains a set B which is parallel in every way to the conditions of tables IX and X, except that 10% of feldspar was introduced in the sand used in F.

TABLE XII.

Data.—Steam Pressure, 150 pounds per square inch.
Temperature in Hardening Cylinder, 185° C.
Time Exposed to Steam, 10 hours.
Molding Pressure, 15,000 pounds per square inch.

Number of test	Composition of mixtures. Parts coarse sand	Parts fine sand (including impurities)	Per cent. feldspar	Per cent. quicklime. Pure CaO	Per cent. quicklime. Dolomitic	When Tested. At once after hardening. Crushing strength	At once after hardening. Tensile strength	After aging. Crushing strength	After aging. Tensile strength	After freezing. Crushing strength	After freezing. Tensile strength	Per cent. water absorption
B*	2	1	0		10	5197	286			5853	314	9.11
F†	2	1	10		10	4619	339			5115	197	6.94

*B is the average of tests Number 112, 113, 114, 115, 116 and 117.
†F is the average of tests Number 124, 125 and 126.

Conclusions.—In studying table XII a slight decrease in crushing and an increase in tensile strength is noted with reference to series B and F. After freezing, F increases in crushing strength, but not at the same rate as B. The marked falling off of the tensile strength after freezing is a disturbing factor, however.

Efflorescence.—The mechanical tests given above would hardly bar a sand which carries as much as 10 per cent. of feldspar. But another objection is liable to arise, namely, the decomposition of feldspar by steam at a pressure of 150 pounds per square inch, resulting in the setting free of potash or soda. This is the more likely to occur since some preliminary experiments have shown the writer that feldspar is really decomposed to some extent by steam at a high pressure. Since the alkalies are soluble in water the danger of efflorescence or scumming would be considerable if any appreciable amount of the feldspar present should be attacked by the lime. Until it has been proven that feldspar does not produce scumming due to the crystallization of soluble salts on the surface the writer would not advise the use of a feldspathic sand if it were desired to produce a first-class product and when working with a high steam pressure.

If on the other hand the feldspar molecule opened up and united with calcium oxide and silicic acid to form a more complex and an insoluble silicate, there would be no danger from efflorescence and we should have a stronger brick for each unit of calcium oxide used in this reaction. The results of the tests made suggest, however, that this complex silicate is not built up, since the brick with feldspar were slightly weaker rather than stronger.

A preliminary experiment showed that quartz was attacked more readily by lime than feldspar was under similar conditions, *i. e.,* 150 pounds steam and ten hours time. From this we might infer that sands rich in feldspar could be worked safely by keeping the steam pressure down to 120 pounds or lower and by not allowing it to remain in the cylinder any longer than is necessary to react with enough quartz for producing the required bond. By working in this way it is probable that not enough feldspar would be broken up to give any trouble later on.

The Effect of Dehydrated Kaolin.—On account of the hydraulic properties developed by mixtures of weakly ignited kaolin and caustic lime under ordinary atmospheric conditions, it was considered advisable to test their behavior under high pressure steam.

TABLE XIII.

Data:—Steam Pressure, 120 pounds per square inch.
Temperature in Hardening Cylinder.—180° C.
Time Exposed to Steam, 8 hours.
Molding Pressure, 15,000 pounds per square inch.

Number of test.	Composition of mixtures.					Tests.	
	Parts coarse sand.	Parts fine sand (including impurities).	Parts burnt kaolin.	Per cent. quicklime.		Crushing strength.	Tensile strength.
				Pure CaO.	Dolomitic		
A8	2	1	....	10	....	8545	....
I 8	2	....	1	10	....	3919	459
B8	2	1	....	....	10	6038	....
J 8	2	....	1	....	10	3110	256

It is readily seen from table XIII that nothing is gained by the use of dehydrated kaolin, since the blocks made with ground flint or fine sand under the same conditions of manufacture developed double the strength shown by mixtures containing it.

THE LIME.

Quantity Required.—The first point to receive consideration in connection with lime is the question of quantity needed for the reaction. In practice, the amount used varies from 5 per cent. as a minimum to about 10 per cent. as a maximum. In order to determine the desirability of using larger or smaller amounts of lime, it was necessary to show whether increases in strength follow increases in lime, and if so whether the increases are proportional. To clear up these points the following series of experiments were made, as shown in Tables XIV and XV.

TABLE XIV.

Data:—Steam Pressure, 150 pounds per square inch.
Temperature in Hardening Cylinder, 185° C.
Time Exposed to Steam, 10 hours.
Molding Pressure, 10,000 pounds per square inch.

Number of test.	Composition of mixtures.				When tested.						Per cent. water absorption.
	Parts coarse sand.	Parts fine sand (including impurities).	Per cent. quicklime.		At once after hardening.		After aging.		After freezing.		
			Pure CaO.	Dolomitic.	Crushing strength.	Tensile strength.	Crushing strength.	Tensile strength.	Crushing strength.	Tensile strength.	
83	3	2	....	5	3697	427	....	....	3812	....	8.06
90	3	2	....	10	5607	503	5843	446	7525	417	9.87

TABLE XV.

Molding pressure—10,000 pounds per square inch.

84	3	2	5	....	2636	194	....	......	....	....	10.25
97	3	2	40	....	7018	541	7153	622	7995	516	12.13

Studying Tables XIV and XV, we observe that in Table XIV, where dolomite lime was used, an increase in lime was coincident with an an increase in strength, but while the quantity of lime was doubled, the increase in strength was only a little over 50 per cent. However, after freezing, the sample high in lime shows an increase in strength of almost 100 per cent. This increase is probably mainly due to the changing of the small amount of free lime which is usually present to carbonate by the carbon dioxide in the water which was used to thaw out the bricks after each freezing. The larger the quantity of lime used in the mixture, the larger will be the quantity which is not converted into calcium silicate in the process.

In Table XV a high calcium lime was used and offers a comparison between the extremes of high and low lime. Thus in No. 97, eight times more lime is used than in No. 84 and it is shown that with an eightfold increase in lime, only a threefold increase in strength was produced.

We might hence conclude from the results, that while there is an increase in strength with an increase in lime, this increase is less marked the higher the lime becomes and that the strength gained by an addition of lime beyond ten per cent. would not justify the additional expense. For this reason we may make the statement that the proportions used in practice represent good economical conditions.

It should be stated here that the per cents. of lime given throughout this paper are based on the raw sand as unity. That is, 5 per cent. of lime means that to 100 pounds of sand 5 pounds of the dry oxide or its equivalent was added.

Kind of Lime Required.—Having decided on how much lime we should use, the next questions which presents themselves are: Will some particular type of lime serve our purpose better than others? Will a hydraulic lime be as good or better than a pure lime? Will a lime made from dolomite be as good as one made from a high calcium limestone?

In view of the fact expressed in table XIII that lime and dehydrated kaolin do not develop any strength under high pressure steam we would infer that steam under pressure is not conducive to the development of the hydraulic properties of a hydraulic lime. We would therefore expect that the calcium silicate of such a lime would be inert so far as the development of immediate strength in a brick is concerned. This may be due to the lack of moisture, since hydraulic lime shows its best strength in contact with water. The hydraulic properties of a lime might develop slowly after manufacture of the bricks and after a longer period, perhaps at the end of a year they might show great strength, especially if the brick were in contact with water. This, however, is still an open question.

Pure limes, carefully burned, are naturally considered the best, since for each unit of weight we have available a greater proportion of the active calcium or magnesium oxide the purer the lime stone is.

Aside from the preceding considerations, we have in most States, two distinct types of limes. In some localities both are available at approximately the same cost, in others there would be a marked difference in price. One of these limes is known as high calcium, high carbonate, hot or gray lime, and is made from a limestone carrying from 85 to 100 per cent. of calcium carbonate, some magnesium carbonate being present frequently. The other variety is known as white lime, dolomite or lean lime and is made from dolomite or dolomitic limestones which at their best carry about 42 to 44 per cent. of magnesium carbonate and 56 to 58 per cent. of calcium carbonate. Thus a molecule of each carbonate is present in a joint molecular structure. Many magnesian limestones containing from 15 to 30 per cent. of magnesia are also found, but are not esteemed so highly as white limes for most purposes.

To test the relative value for the sand-brick reaction of these well marked commercial varieties of lime, the following tests were undertaken.

TABLE XVI.

Data:—Steam Pressure, 150 pounds per square inch.
Temperature in Hardening Cylinder, 185° C.
Time Exposed to Steam, 4 to 14 hours.
Molding Pressure, 15,000 pounds per square inch.

Number of test.	Composition of mixtures.				When tested.				Per cent. water absorption.
	Parts coarse sand.	Parts fine sand (including impurities)	Per cent. quicklime.		At once after hardening.		After freezing.		
			Parts CaO.	Dolomitic.	Crushing strength.	Tensile strength.	Crushing strength.	Tensile strength.	
A*	2	1	10		7745	437	9007	371	8.62
B†	2	1	..	10	5187	286	5853	314	9.11

*A is the average of tests Number 106, 107, 108, 109, 110 and 111.
†B is the average of tests Number 112, 113, 114, 115, 116 and 117.

Twelve blocks were tested in A, and an equal number in B, all made in exactly the same manner, with the exception that in A a high-calcium lime was used, and in B, a white or magnesian lime was used.

The differences shown in Table XVI are very marked, the use of dolomite lime resulting in a loss in strength, both crushing and tensile, of more than one-third. Another noticeable fact is that the water absorption is greater in B than in A. Why the dolomite limes give a weaker brick is still an unsolved problem. Since MgO is at least equally active as CaO in attacking SiO_2, we can only infer that the magnesium silicate formed is a much weaker bond than the calcium silicate. This is also supported by the fact that there is also more combined water in brick made from sand and dolomite than in those made from sand and high calcium or hot lime.

It is evident therefore that the high calcium or hot limes should receive the preference in selecting materials for this industry, where both types of lime can be laid down at the plant at the same cost. There are two reasons as is clearly indicated above, *i. e.*, it is easier to procure complete hydration, and the resultant product is stronger for each unit of lime used. However, in localities where dolomite lime is cheaper than hot lime it might be desirable to use the former.

PREPARATION OF THE RAW MATERIALS.

Now that the requirements which raw materials must possess in order to be satisfactory have been set forth the next step will be to determine what preparation they will need.

The Sands.—Beginning again with the sand, if our source of supply is a soft sand rock it will need to be crushed and the individual sand particles separated. The question of the machinery best adapted to this purpose will depend to some extent upon the nature of the rock to be reduced. If we have to deal with a sand obtained by dredging, it will usually be quite wet and must at least be partially dried, since a large amount of water is undesirable in the mixture. The degree of drying necessary will be dependent upon the subsequent treatment prior to pressing.

In case of the presence of too much clay or of soluble salts deposited by sea-water, as would probably be the case with seashore sand, it would be necessary to roughly wash the sand. In the first case the clay is floated off and in the second case the salts are again taken into solution and thus removed. The arrangement for accomplishing this result will depend almost entirely on local conditions. Again if the sand does not contain any very fine quartz it will be necessary to pulverize a small portion of it. For this purpose a tube or ball mill is very desirable since these machines produce a product of very great fineness. The Griffin mill is also a very satisfactory apparatus for the purpose. However, in many cases it will not be necessary to resort to this fine grinding, as the sand frequently contains enough of this finer material.

Roasting the Sand.—In foreign countries it has been claimed by a few persons that it is advantageous to roast the sand. The advocates of this procedure claim that chemical combination is rendered more rapid and complete by giving the sand a preliminary roasting. It is doubtful if the activity of the sand is increased sufficiently to justify this additional expense, but the exact value of roasting the sand remains yet to be determined.

The Lime.—Assuming, that we have a comparatively pure lime, properly burned, it must be hydrated, or, in popular terms, it must be slaked either before adding the sand or in connection with its incorporation into the sand. Owing to the slow slaking properties of magnesian limes they could not be safely used unless they had been slaked prior to the addition of the sand. The slaking of the lime and the incorporation into the sand mix involve the main differences between the various processes or systems in use. The essential feature of each system is generally the use of some special piece of machinery or some special manipulation, for this purpose.

Slaking.—The slaking of lime is in one sense a very simple process, consisting in the addition of water to calcium oxide, or a mixture of calcium oxide and magnesium oxides, which enter into chemical combination with a certain proportion of the water. One would hardly suppose that so simple and well known an operation should form the ground for the issuance of a large number of patents. Such is the case, however, both in this and in foreign countries. This is probably due to the fact that a chemical reaction is involved and in many cases a reaction will not complete itself except under certain conditions. This is in a large measure true with the slaking of lime. Too much or too little water will yield an inferior product.

Most of the patents, however, are for methods or machines which utilize the heat generated in hydration to dry out any excess of moisture and leave a product which is easily handled and stored without loss to its activity.

While there are a large number of lime slaking processes which differ from each other only in detail of manipulation, there are in reality only two distinct procedures:

1. The time honored method of slaking to a putty with a slight excess of water. This is used either in the putty form or after drying and grinding.

2. The other which slakes to a dry powder. This is accomplished by adding only a little more water than will be chemically combined, so that the excess will be removed by means of the heat generated on the hydration of the oxides. The resultant product usually carries a little less water than that called for by theory, yet there seems to be no heating or expansion after the subsequent addition of water in using it.

The limes prepared by one or the other of the preceding processes will, in the nature of the case, govern the subsequent handling of the sand to a considerable degree, since one is a tough, plastic, sticky mass and the other a dry powder. However, the method of slaking should be a function of existing conditions, and that method should be selected which will best adapt itself to the process which has been decided upon for good reasons. In order to make this clear we will cite one or two specific cases.

Case 1. Wet sand. We will assume that we are dealing with a wet sand. If it were quite wet we would dry some of it and add the unslaked lime to the wet portion, provided we had a high calcium lime to work with, correcting the moisture by adding sand, wet or dry, and lime as the case might require.

Case 2. Moist sand. Slake the lime to a putty and mix with the sand. This has its drawbacks on account of the extreme difficulty of getting a small amount of tough sticky matter distributed evenly throughout a mass of quartz grains. In the opinion of the writer, however, it has the great advantage of requiring less pressure in the die of the machine to develop the maximum strength than is required by the dry process. The writer is inclined to believe that the increased cost of mixing would more than cover the expense of drying the sand. If the lime is to be used in the putty state it will always be found advantageous to work up all the water that is to be added to the mixture into the putty first, making the lime into a slurry or slip and thus facilitating distribution.

But if there is much water in the sand, the water left to be added to the lime is so small that it does very little good.

Case 3. Dry sand. This is the easiest to operate, since the dry sand and the dry hydrate or dry ground quicklime can be readily mixed to a fairly homogenous mass and the water can then be incorporated without difficulty. The water will be distributed still more uniformly if after the mixing the whole mass is allowed to stand in a bin or pile for a short time. While standing in a pile or bin does undoubtedly unify the moisture distribution, practice seems to indicate that it is unnecessary and frequently troublesome owing to the tendency to cake together in the bin or silo. A number of plants which originally used a silo system have abandoned that phase of practice in the process of manufacture.

The facility with which a uniform mixture can be produced from the dry ingredients led us to adopt case three as the means of preparation for all the materials used in our experimental work.

In the work intended to determine what requirements a good brick press suitable for this industry would have to fulfill, material prepared according to case three above was used. The results obtained will therefore apply strictly only to that class of materials. However, the writer feels that any press which is satisfactory for case three, will answer all the requirements for any of the others.

CHAPTER III.

THE PRESSING AND HARDENING.

PRESSING.

The writer did not agree with the popular belief that the harder a brick was pressed the denser it would be, or rather it was felt that there was a limit beyond which the increase in strength of the brick would justify the additional cost of construction and operation of the press. In order to arrive at some idea in regard to this property of sand-lime mixtures, blocks were first made on a screw hand-press, such as is used for making encaustic tile, by applying several successive pressures. After hardening, these blocks were crushed and compared with duplicates made with one pressure. The repetition of the pressures gave a very decided increase in strength. It also indicated that insufficient pressures were being obtained. Since it was not possible to control accurately the pressures generated in a machine of this type, the screw hand-press was abandoned. Its place was taken by a press, improvised from a Tinius Olsen testing machine; the die was filled, and the top and bottom plungers inserted, and then placed between the two plates of the machine, which was adjusted for crushing work. By this means, the plungers would be slowly forced towards each other, compressing the charge in the die to any desired extent. The conditions as regards regulation of pressure and studying the compression and expansion of the material under treatment were ideal.

From the moment of inertia of the head-wheel and the pitch of the screw of our hand-press it was calculated roughly that we were getting a pressure of from 5,000 to 7,000 pounds per square inch. We therefore took 5,000 pounds per square inch as the starting point of the tests made on the Olsen machine and made a series of blocks, using 5 per cent. of each type of lime and the same sand mixtures, and employing pressures of 5,000, 10,000, 15,000 and 20,000 pounds to the square inch. All these blocks were hardened in steam at 150 pounds pressure, for ten hours. The blocks were then subjected to crushing tests.

The results of this work are plotted on Plate I. The loads at which the test blocks crushed are shown by the ordinates and the pressures employed in the manufacture by the abscissae. All values are expressed in pounds per square inch. The two lower curves illustrate this group of results. It is seen in both cases that the highest crushing strength

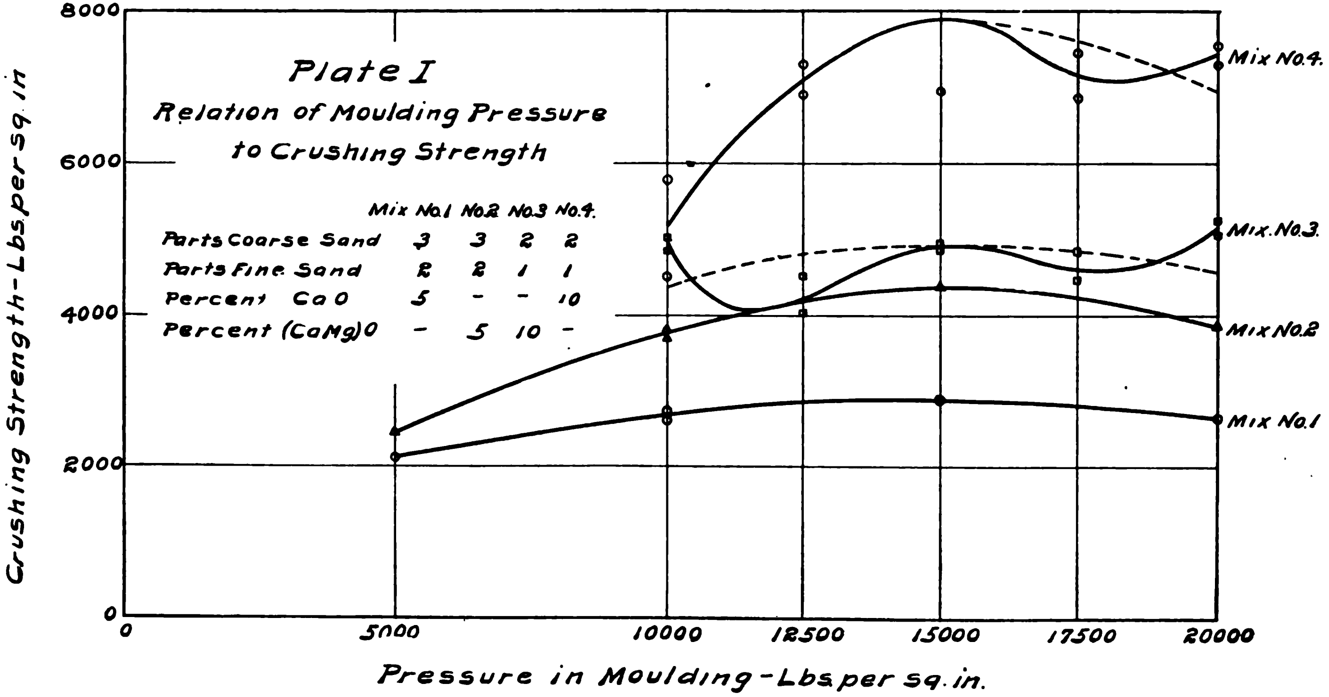


Plate I

Relation of Moulding Pressure to Crushing Strength

	Mix No.1	No.2	No.3	No.4.
Parts Coarse Sand	3	3	2	2
Parts Fine Sand	2	2	1	1
Percent CaO	5	-	-	10
Percent (CaMg)O	-	5	10	-

is obtained at a brick-press pressure of about 15,000 pounds per square inch with a slight falling off at 20,000 pounds.

Realizing the importance of this determination, it was thought, since the intervals were 5,000 pounds to the square inch, that, although the curves seemed regular and pointed pretty closely to 15,000 pounds as the best pressure, the most desirable pressure might be on one side or the other of this figure. For this reason a new set of test blocks was prepared with different intervals. It was evident from the first curves that it was not necessary to go below a pressure of 10,000 pounds to the square inch. This set, as shown in the two upper curves of plate I, began with a molding pressure of 10,000 pounds and was increased by increments of 2,500 pounds to 20,000 pounds per square inch. Ten per cent. of a high calcium lime was used in one set, and ten per cent. of magnesian lime in the other. The upper curve, No. 4, represents the blocks made from the high calcium lime, and the second curve, No. 3, the magnesian lime. Duplicates of each kind were made at each pressure.

Here again in the upper curve, No. 4, the highest point is found at the 15,000 pound pressure and just a little lower for the 20,000 pound, with a marked depression at 17,500 pounds. The second curve, No. 3, is a very irregular one, with 10,000 and 15,000 pounds on a straight line and 20,000 only a trifle stronger, with depressions at 12,500 and at 17,500. Making a smooth curve, as indicated in both by a dotted line, taking 15,000 pounds as high point and averaging through, we obtain curves almost parallel with the two lower curves.

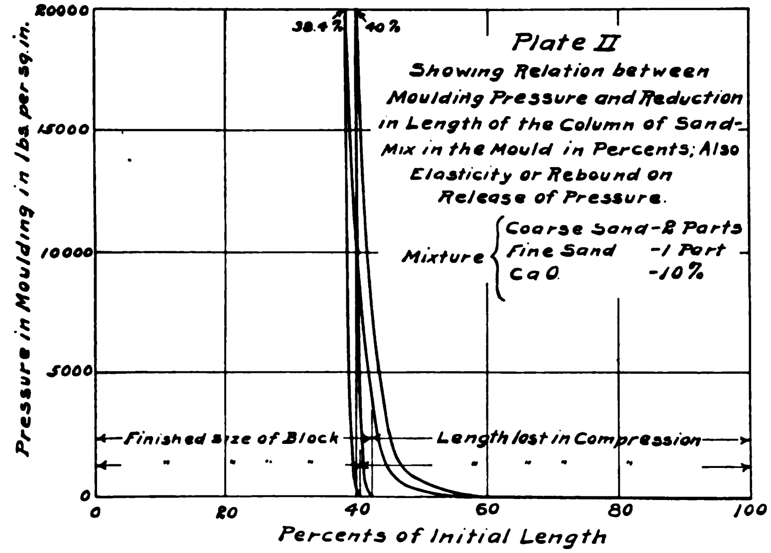
The writer would like to see more extensive tests made on this point, reducing the intervals of pressure to 1,000 pounds per square inch. However, it seems that there is sufficient evidence to enable us to say that the best pressure is close to 15,000 pounds to the square inch.

It requires a pressure of about 75 pounds per square inch of surface exposed to the sides of the molds to start a brick out of the mold, when the latter is made of cast iron, after a pressure of 15,000 pounds per square inch has been applied. This of course will be much less with hardened steel linings. This reduction in the friction will also slightly lower the pressure necessary in pressing. When low pressures are used the top and bottom are harder than the center and the difference when using soft molds is sufficient to be readily observable.

This work should furnish some suggestions for the dry-press brick-machine manufacturers, and it would be desirable if the same points were taken up in regard to the dry pressing of clay products.

Behavior of Loose Powder in Mold.—The next consideration was the behavior of the loose powder in the mold. The same mixtures were used as in the preceding case, namely, 2 parts of coarse and 1 of fine sand with 10 per cent. calcium oxide (CaO) added in one case, and 10 per cent. dolomitic lime (CaMgO) in the other.

The curves of Plate II show the facts as taken from the Olsen autographic plate. Measurements were also made of total compression and



length after the pressure was removed. These were almost identical for both cases at the various pressures, 5,000, 10,000, 15,000 and 20,000 pounds. The elasticity or expansion shown was greatest at 15,000 and 17,500 pounds, least at 20,000 pounds. The difference was only from 0.01 to 0.02 of an inch.

The curves shown in Plate II cannot show the recoil at any pressure except the maximum, but do show the rate of compression for any pressure. The longest curve was evidently due to not getting so much material into the mold, since it compressed beyond the point it should have reached, giving a curve parallel to its duplicate. Compression to 61.3 per cent. is accomplished with practically no load and from that point on the load increases very rapidly with each shortening of the block. The compression is less than 0.01 inch per inch of length for the addition of 5,000 pounds to 15,000 pounds. The total compression was 40.9 per cent. at 20,000 pounds, springing back to 42.9 per cent. as final size. The curves produced when the calcium oxide was replaced by dolomite lime were so near to duplicates of the above as shown in Plate II, that it seemed unnecessary to reproduce them. The behavior of the two mixtures in the mold was almost identical.

For different mixtures of sand the compression will no doubt be somewhat different, but will probably follow nearly the same curve, taking the load very rapidly after a pressure of 2,500 to 3,000 pounds is reached.

The press will be considered further under the head of mechanical equipment.

THE HARDENING.

Hardening Kettles.—In this connection the writer wishes to urge on all prospective builders of plants the necessity of careful and safe construction of the device for holding the head of the hardening kettle. Where accidents have occurred it has usually been due to some defect at this point. The manner of fastening the bolts to the boiler should be carefully looked into and no chances taken, since loss of life and destruction of property are sure to follow any carelessness in this direction.

It was known that good strong brick could be made in ten hours with a steam pressure of 150 pounds per square inch. It was not known to the writer how much less pressure would do the desired work. Nor was the relation between pressure and time of exposure known; *i. e.*, whether a shorter exposure at high pressure would do the same work as a longer exposure at lower pressure and vice versa. In order to obtain data on this point, experiments were made as shown in Table XVII. The pressure used in making the blocks was 15,000 pounds per square inch, throughout.

TABLE XVII.

Steam Pressure, 150 Pounds.

Hours in steam.	A		B		C		D		E	
	Crushing strength.	Tensile strength.	Crushing strength.	Tensile strength.	Crushing strength.	Tensile strength.	Crushing strength.	Tensile strength.	Crushing strength.	Tensile strength.
4	7896	544	5303	392	5282	591	4514	470	4441	330
6	7994	390	5045	199	....	....	......	....	....	.....
8	7404	509	4957	262	6170	632	4249	430	4491	337
10	7767	464	4902	284	....	......	....	....	....	....
12	7514	337	5064	250	6165	556	4543	434	4924	349
14	7894	380	5849	329	....	....	....	....	....	....

Steam Pressure, 120 Pounds.

Hours in steam.	A Crushing strength.	A Tensile strength.	B Crushing strength.	B Tensile strength.	C Crushing strength.	C Tensile strength.	D Crushing strength.	D Tensile strength.	E Crushing strength.	E Tensile strength.
4	6989	....	5989	....	5403	....	4300	....	5760	....
6	7063	....	6495	....	....	....	.....	....	.....	....
8	8545	....	6038	....	5868	....	5142	....	6718	....

Steam Pressure, 100 Pounds.

Hours in steam.	A Crushing strength.	A Tensile strength.	B Crushing strength.	B Tensile strength.	C Crushing strength.	C Tensile strength.	D Crushing strength.	D Tensile strength.	E Crushing strength.	E Tensile strength.
4	6385	....	5921	....	4280	....	4048	....	4588	....
8	7566	....	6507	....	5564	....	4456	....	6544	....
12	7494	....	5753	....	....	....	....	....	....	....

The main result arrived at was that four hours at 150 pounds steam pressure is sufficently long for making good bricks while 6 to 8 hours are required at 120 pounds, and 8 to twelve hours at 100 pounds.

The samples which contained 10 per cent. of feldspar (F) showed a marked increase in strength in each case where the time was longest. This fact is noted since it suggests that long exposure in steam probably results in the final breaking up of the feldspar and in case it did so might produce effiorescence owing to the setting free of the alkalies. Also, knowing this fact, it might probably be desirable not to hold a material containing much feldspar in the kettle any longer than necessary.

It is probably general practice to use 120 pounds steam pressure and to maintain it from 8 to 10 hours. In the light of the experiments made by the Survey this is good practice. It usually takes about one hour to get up the pressure and another to blow off and cool down sufficiently for removing the cars. The time required to raise the temperature will, of course, depend on the steam capacity of the plant, the size of the inlet pipe, etc. If the pipes are large enough and there is sufficient steam capacity, the temperature can be safely brought up very rapidly. The writer has put green brick into the experimental kettle described in the beginning of Chapter I, at a temperature of 130° C., and in about five minutes turned on the steam, bringing the pressure up to 150 pounds in ten minutes more without any apparent injury to the bricks. However, the brick on which this test was made carried only five per cent. of moisture.

CHAPTER IV.

TESTING.

The testing of the products was in the main mechanical. However, chemical methods were tried in a number of cases, and enough results were obtained to show how much dependence may be placed on this method as an indication of the quality.

Crushing Strength.—The mechanical test is always best whenever it is feasible to make it. The results appeal more strongly to the public even if the chemical tests were equally accurate, which is probably not the case, since the physical structure of the mixture has a decided influence on the strength, regardless of the amount of bonding material. An automatic, autographic, Tinius Olsen testing machine, driven by power, was used for all tests.

The autograph was only used once on each type of material, since more satisfactory and rapid work could be done without the autographic attachment on the machine. A ball and socket head piece was used, as well as pasteboard, to take up any unevenness of the blocks in all cases, except those on which curves were to be taken.

The crushing strength and tensile strength was determined in each test. Two to three blocks were crushed in most cases, and the average reported. For the tensile strength, when two were pulled, the average is given. Every brick made was tested, so that the results represent the whole knowledge gotten, and not merely the best results selected out from a number.

A few of the bricks made were set away in a dry room for determining the effect of age. These were duplicates of bricks which had been tested, so that by comparison any material change could be observed. There was no marked change in strength after forty days' exposure to dry air, except in the specimen carrying 20 per cent. of kaolin. This test piece showed considerable weakness. If these brick had been moistened from time to time they would have shown increased strength. This is due to the fact that carbon dioxide acts very slowly, if at all, on dry calcium hydrate. The above test is of no special importance unless it were carried out for several years, at least, and on a large number of samples.

The appearance of the cubes after coming from the crushing test is well shown in Figure 3, below. The sharp brittle fracture shows that the material broke like a good natural rock does. The lower row of rounded masses were cubes made with sand and lime mortar. They developed low crushing strength, as their appearance indicates.

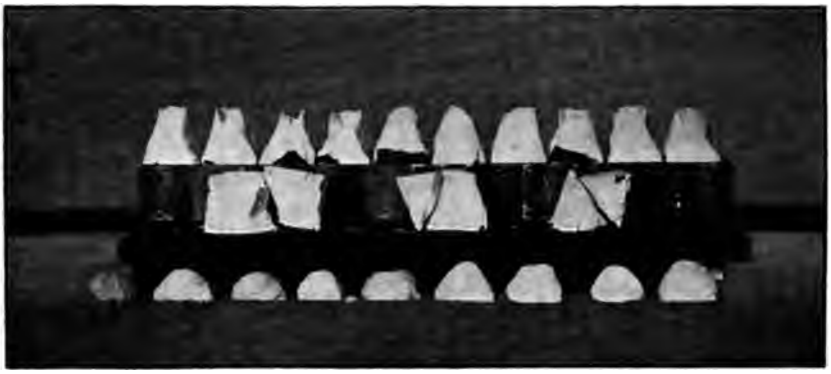


Figure 3.—Sand-lime cubes after crushing test.

The Freezing Test.—This test was made a very severe one. Duplicates of the blocks which had been tested were used. The brick used in the freezing test were made under exactly the same conditions as those which were tested under normal conditions. They stood about two weeks after hardening, before they could be frozen.

The test was carried out in the following manner: The lot of blocks to be tested were weighed, dried at 110° C., weighed again, then soaked for 48 hours in water and finally weighed once more. The water absorbed was figured in per cent. of the dry weight of the brick. They were then placed, while still saturated with water, on a rack and lowered into an ice can which was anchored firmly in the freezing brine. The temperature of the brine ranged from 12° to 15° F. They were frozen to the center in less than four hours, but were never taken out in less than that time. In this fully frozen condition they were lifted out and dropped at once into another can containing water at a temperature of 95° to 105° F. and thawed out completely. The interval required was less than two hours—but this much time was always allowed. They were then lifted from this can and while still wet dropped at once into the freezing receptacle. This alternate freezing and thawing was repeated 21 times on all blocks tested.

As a matter of curiosity, three cubes were put into distilled water and the water was then frozen solid; this treatment was repeated several times. The cubes showed no sign of breaking down at the end. These were not tested.

The material after this severe treatment was further abused by being dried out at a temperature of 125° C., after which it was tested.

Quite a number of results have been given in the tables VI, VII, VIII, IX, X, XI, XII, XIV, XV and XVI in such a way as to compare frozen with unfrozen material, and the facts have in a measure been brought out prior to this statement.

The blocks, almost without exception, as is seen by going over the tables, showed a marked increase in crushing strength, and in some cases an increase in tensile strength as well. Usually the tensile strength was slightly less, if any material change in the crushing strength had taken place. However, we did not always have duplicates on the frozen briquettes.

The reason of this increase in strength must be due to one of two causes:

1. The lime was not all combined with silica (SiO_2) and this uncombined lime took up carbon dioxide (CO_2) from the water in which they were thawed out. This is very likely from three reasons. First, the calcium is seldom completely converted into silicate except when using very small quantities of lime such as 2 to 3%. The higher the per cent. of lime used the greater will be the amount as a general rule which is not transformed to the silicate condition. Since 10% of lime was used in most of the samples examined, it was certain that some lime would be present in some form other than as a silicate. The most probable form for this lime would be the hydrate· Second, the water was drawn from a deep well near Columbus, Ohio, and I know from previous experience that these waters are rich in calcium and magnesian salts, and also carry much carbon dioxide in solution. Third, the specimens which were highest in lime showed the greatest increase in strength after freezing.

2. In case the calcium hydro-silicate formed has hydraulic properties (which I doubt), these properties would be developed by constant soaking in water and would naturally result in the development of more strength. I think, however, if the strengthening action were of a hydraulic nature, it would be most marked in the tensile strength rather than the reverse.

CHEMICAL METHODS.

The first work done was to see whether the determination of the percentage of silica rendered soluble by the steam treatment in hardening, gave any light on the strength of the product. It might very naturally be assumed that high per cents of soluble silica, where none existed before, would indicate the formation of a hydro-silicate bond in large quantity and this again would indicate strength. The results of this test are also shown in the following table:

TABLE XVIII.

Number.	Crushing strength pounds per square inch.	Tensile strength pounds per square inch.	Soluble silica per cents.	Per cent. water absorption.
89	2260	238	1.57	10.36
90	5607	503	3.66	9.87
92	4729	599	4.09	10.91
87	1943	184	1.77	8.50
110	7514	337	3.10	8.80
116	5064	250	3.17	9.01
120	6165	556	4.01	6.01
123	4543	434	3.46	8.27
126	4924	349	4.07	7.34

The table above makes it clear that neither the amount of soluble silica, nor the degree of porosity, can serve as a true guide to the strength of sand-brick. The soluble silica could be used merely as an indication. The writer would be afraid of a sand-brick which did not have at least two per cent. of soluble silica, no matter how well it might appear.

The second test on chemical lines was to determine, if possible, the nature of the hydro-silicate which is formed between the lime and the sand, and which forms the bond of the artificial stone. A number of the different briquettes were treated with dilute hydrochloric acid and sodium hydroxide, on the general method used in the rational analysis of clays. The substances taken into solution would naturally be, 1st, free calcium oxide, hydroxide, or carbonate; 2d, calcium hydro-silicate formed in the hardening process; 3rd, soluble silicic acid, not combined with calcium or other bases; 4th, ferric oxide in the original materials. The solutions obtained in this manner were then analyzed in the usual manner with the following results:

TABLE XIX.

Analysis of the Portions of Sand-lime Bricks Soluble in Hydrochloric Acid and Sodium Hydrate.

Number................	75	76	110	116	120	123	126
Silica (SiO_2)	2.59	2.71	3.10	3.18	4.02	3.47	4.08
Alumina–Ferric Oxide..	0.32	0.14	0.25	0.15	1.63	1.38	0.44
Calcium Oxide (CaO)..	3.90	2.69	6.30	4.81	5.57	4.94	4.87
Magnesia (MgO).......	0.21	1.01	0.97	1.91	0.81	2.87	1.66
Totals.................	7.02	6.55	10.62	10.05	12.03	12.66	11.05
Press Pressure.........	10,000	10,000	15,000	15,000	15,000	15,000	15,000
Steam Pressure........	150	150	150	150	150	150	150
Hours Duration of Steam Treatment. .	10	10	12	12	12	12	12

Numbers 120 and 123 contained clay in their mix, and No. 126 contained feldspar. The evidence furnished by this table is insufficient for a determination of the constitution of the bonding material in sand brick. It is, however, suggestive and points to a bi-calcium and a bi-magnesium silicate. Calculating on this basis, the samples low in lime have an excess of soluble silica, and the ones high in lime an excess of lime. A large number of analyses, including a determination of the combined water and the carbon dioxide, and the free lime will be necessary before any safe conclusion can be reached as to the exact constitution of the bonding material. Thin sections under the microscope will also likely aid in identifying the silicate formed.

CHAPTER V.

PROPERTIES OF THE PRODUCT.

Concerning the quality of this new artificial stone, the question arises in the mind of many: "Is it of any value to us?" "Will it fulfill our requirements for a safe and desirable building material?" In the writer's opinion this question should be answered in the affirmative. Reference to tables IX, XII, XVI and XVII shows that abundant evidence is offered that not only a strong but also a durable material *can* be produced. Crushing strengths as high as 8500 pounds per square inch, with averages of 7,700 pounds, and tensile strengths of 550 pounds per square inch, with averages above 425 pounds per square inch, are shown. Further, the strength is shown to be greater after exposure to frost and weather, rather than weaker. It may be objected by sceptical persons that these results were not obtained in a regularly manufactured product, but merely in small two-inch cubes, made under conditions which cannot be duplicated in commercial practice Reference to the conditions of manufacture show that in size of product only does this test material differ from that of commercial plants. In kind of materials employed, in proportions of the ingredients, in methods of mixture, in amount of mechanical pressure, in temperature and pressure of steam, in duration of steam treatment, the conditions were made to conform to practice in existing plants. Naturally, these conditions were varied, in order to learn the effect of variations, but this in no way diminishes the credibility of evidence gotten in the regular way. It was not possible, with the apparatus available, to make and study full size material, but there is less likelihood of differences in structure due to differences in size, in sand-lime brick than in any other material of which brick are made, as the mixture is practically non-plastic, and granular, and packs under pressure to a dense, even body of great homogeneity. It seems, therefore, that very little abatement need be made in the quality of the results from the small size of the bricks made; in fact, commercial sizes should give better results instead of worse.

These tests show what *can* be done by this process.

The following may be cited as an evidence of what is actually being done in a commercial way.

On a sample made in Germany, by the Stahl and Eisen Actien-Gesellschaft, Höerde, Germany, from materials which were not the most desirable, an analysis by rapid methods gave:

84 per cent. SiO_2 (sand and soluble silica .
2 per cent. $Fe_2O_3+Al_2O_3$
7 per cent. CaO
per cent. MgO low.

---

93 per cent.
7 per cent. Balance is made up of MgO, H_2O, CO_2 and alkalies.

When three grams were ground fine and treated with a large amount of water, only a trace of lime was found in the water.

The water absorbed on standing over night is 9 per cent. A small piece was soaked in water, frozen and thawed three times. It was thawed out the last time on the laboratory hot plate at about 250 degrees C. The writer could observe no evidence of damage by frost except when it froze fast to a sandstone window-sill, and broke off a little when wrenched loose. After thawing out, and while still wet, a blast lamp was turned directly onto one small piece of it, which was brought up rapidly to a bright red heat, and held there for fifteen minutes, and then finally plunged into cold water. This last procedure destroyed the bond on the surface, but did not affect the interior. A block sawed from this brick and crushed showed a crushing strength of 4,210 pounds to the square inch.

Further in a paper given by Herr G. Beil, of Aschersleben, at a meeting of the Kalksandstein Society in Berlin, March, 1901, the following results are given as coming from The Koenigl. Mechan-technischen Versuchsanstalt, at Charlottenburg, Germany.

Seventy brick, representing 7 different products, were soaked in water at 12° to 15° C., frozen for four hours, then placed in warm water three hours. All were pronounced sound at the end.

Also the following list of tabulated results (published in Vol. 25 *Ton-Ind. Zeit.*, 575) is of interest:

TABLE XX.

Number of test.		Absorption.	Crushing strength, in pounds per square inch.		
		Amount of water taken up by dried sample, after 125 hours soak, in per cents of dry weight.	Water soaked brick.	Dry brick.	After freezing.
1	High pressure hardening.	12	1903	1704	2229
2		14	2073	2215	2300
3		9	3933	4189	4260
4		10.6	1846	1732	2187
5		....	....	3710	3238
6	Low pressure hardening.	....	....	850	1335
6*a*		....	....	1353	1747
7		18.3	1335	1193	1562

This shows that the crushing strength is not, in most cases, decreased by freezing. Crushing in the wet condition produces a slight decrease, in some cases.

In the *Ton-Ind. Zeit.*, Vol. 25, p. 1660, the following tabulated results are to be found:

Swedish brick, tested at Gothenberg by the same method as in the above Table XVIII.

TABLE XXI.

Kind of brick (all lime-sand).	Specific gravity in powder form.	Actual specific gravity.	Percentage absorption.	Porosity in per cents of volume.	Number of brick tested.
1. Smooth, gray-white.....	2.51	1.74	13.1	30.5	10
2. Yellow-brown to red. ..	2.46	2.10	13.6	14.6	10
3. Smooth, gray-white.....	....	....	....	....	4
4. Brown-red.............	....	....	....	....	4

	CRUSHING STRENGTH IN POUNDS PER SQUARE INCH.								
	Dry.			Wet.			Frozen repeatedly.		
	Max.	Min.	Mean.	Max.	Min.	Mean.	Max.	Min.	Mean.
1. Same as above.........	1732	1221	1548	1590	1037	1321	1491	724	1193
2. Same as above.........	1463	753	1108	1448	636	980	1164	923	1008
3. Same as above.........	2741	1519	2286	.....	.....	.....	.....	.....	.....
4. Same as above.........	2158	1235	1562	.....	.....	.....	.....	.....	.....

The process of manufacture of these bricks was not stated. This again shows a slight decrease in crushing strength after repeated freezing.

Mr. Brown, of Coldwater, Michigan, has obtained tensile strengths as high as 650 pounds, but gives as an approximate average for bricks made with 10 per cent. lime, from 400 to 425 pounds. He thinks the maximum tensile strength is obtained with very fine sand and about fifteen to twenty per cent. of the hydrated dolomite lime equivalent to nine to thirteen per cent. of the oxides.

A two-inch cube made by Mr. Brown from finely ground sand and dolomite lime, gave a crushing strength of 5730 pounds to the square inch when crushed in the mechanical laboratory at Ohio State University.

Still further data are furnished by the following certificates of testing sand lime brick at Zurich, Switzerland, and Boulogne, France:

TABLE XXII.

1. RESULTS OF CRUSHING TESTS OBTAINED AT THE [illegible] LABORATORY.

Condition of bricks.	Dry.	Wet.	Frozen 25 times at [illegible]
Crushing strength, pounds per 1 square inch	2830	2236	2236

Ten bricks were tested in each case.

2. EXTRACT OF THE REPORT CONCERNING THE TRIALS OF THE EXPERIMENTAL STATION AT BOULOGNE, FRANCE, REGARDING THE RESISTANCE OF SAND-LIME BRICK TO THE ACTION OF FRESH WATER AND SEA-WATER.

Twelve entire bricks and twelve bricks cut in two were immersed in the four following media, by reason of three samples for each medium:

1st. In fresh water conserved in tanks in the cellar of the laboratory and renewed every week.

2nd. In sea-water similarly kept and renewed.

3rd. In the sea itself at the extremity of one of the jetties of the port of Boulogne, where they remained constantly submerged.

4th. In the sea at the extremity of the same jetty at a point where they were alternately bathed and uncovered at each tide.

CONCLUSIONS OF THIS REPORT.

1st. In the bricks thus studied the greater part of the lime added to the sand seems to have combined chemically with a part of the silica contained in the latter.

2nd. When brought into contact with water the composition thus formed seems to be more stable than the silicates of lime usually employed in hydraulic binding agents.

3rd. After three months of immersion the bricks exposed both to the action of sea-water and that of ordinary water were still in perfect condition.

R. F[illegible]

Boulogne, 14th of January, 1901. *The Chief of the Laboratory.*

The following is a copy of tests made on brick manufactured by H. H[illegible]:

TESTS OF SAND-LIME BUILDING BRICK MADE FOR [illegible], 405 WOOD STREET, PITTSBURG, PA., BY THE PITTSBURG TESTING LABORATORY, OCTOBER 17, 190[illegible]

TABLE XXIII.

Crushing strength per square inch.	Absorption test 45 hours in water.	Absorption after freezing test.	Crushing strength per square inch after freezing.
3513 lbs.	11.6% gain.	12.4% gain.	*4157 lbs.
4192 lbs.	8.5% gain	8.8% gain	*5202 lbs.
3530 lbs.	11.3% gain	11.4% gain	

*Bricks did not crush at this load but showed only slight cracks at an actual load of [illegible] pounds, the limit of the machine.

Half bricks were used in absorption tests; these bricks were dried thoroughly before immersing in water. After remaining in water forty-five hours the bricks were frozen four hours at at a temperature of 14° Fahr., and then thawed in warm water twelve hours, frozen again at a temperature of 9° Fahr., for a period of three and one-third hours, thawed in hot water three hours, frozen at a temperature of 12° Fahr., for three and one-third hours, and finallv thawed in hot water for twelve hours. A final absorption test was made and then the bricks were again thoroughly dried. The bricks showed no signs of cracking or disintegration.

The following is a copy of a test made for the Schwarz System Brick Company.

CRUSHING TEST OF SAND-LIME BRICK.

No. 1—Mark—1 piece of brick, size 3x4 in.; area app. 13 sq. in.
Crushed at—35,675 lbs.
Crushing strength per sq. in.—2,770 lbs.

No. 2.—Mark—Full brick, size 4.3x7.7x2.4 in. Area—37.41 sq. in.
Crushed at—96,100 lbs.
Crushing strength per sq. inch—2,570 lbs.

Both of the above specimens were tested flat.
Respectfully, (Signed) CHAS. F. MCKENNA.

Fire Tests of Sand-lime Brick.—From the foregoing it is evident that any of the bricks made under high pressure steam have strength to meet all ordinary requirements for building purposes. In Germany a great many of the fire inspectors have pronounced them a safe material from their standpoint, and a good many sand-brick have gone into municipal and government buildings there. The railroads are also using them.

The following was taken from *Ton-Ind. Zeit.*, Vol. 25, p. 1822:

> A small oven was built of bricks hardened by steam at high pressure, made by Guthemann, of Niederlehme, some whole and some bats. It was fired up by wood up to a temperature of 1100 degrees C., measured both by Seger cones and by the electric pyrometer. The bricks were not injured in any way by this treatment, and further showed that they were excellent non-conductors of heat.
>
> Later, by means of a blast, the furnace was brought to a glowing heat and the hose turned directlv on to the hottest part with a full stream. This cracked off a few corners. When thoroughly cooled it was found that the bond had been destroyed for a depth 3 cm.=¾ in., so that part could be scraped off with a knife.

The writer made the following experiment:

Five blocks representing sand brick of five different compositions were placed in a muffle kiln, and the temperature brought up rapidly until Seger cone 6 was down. Eight or ten hours was required in getting the temperature. The blocks were taken out while still warm. All the blocks were found to be perfect. The only change observable was that they were whiter and had taken on a semi-vitrous lustre. There was no fire shrinkage or expansion. The blocks when cool were exactly the same size as when put in. Ten per cent. of lime was used in each case and both high calcium and magnesian limes were represented, as well as ten per cent. kaolin and ten per cent. feldspar mixtures.

Not satisfied with this, the muffle was brought to a white heat and five more blocks representing the same five mixtures were put in on top of the muffle and the heat continued to cone 6 or 8. These samples contained but 5% of lime. Before the muffle was entirely closed all the blocks which contained either clay or feldspar bursted. Those with pure quartz sand, and lime or magnesian lime, stood the test satisfactorily. The only change again was that they were whiter and more porous, due to loss of combined water, and not so hard since with only 5 per cent. lime the points at which the amorphous silicates would form was not reached. This shows clearly that bricks made from comparatively pure quartz sand will stand a very high heat without injury, since even if the small amount of calcium silicate present were made fluid by heat unless great pressure is applied there would be no deformation. The mass of sand particles built up and wedged in place would not require much bond to hold them together.

Nothing was done to determine the expansion while hot, but with low lime content it would not be far from that of pure quartz, and about the same as that of silica brick.

The Ohlemacher Brick Company, of Michigan City, Indiana, have in their possession a letter from the firm of Prof. Dr. H. Seger and E. Cramer, who conduct a chemical laboratory for clay industries at Berlin, Germany. It states that a sand brick tested, the composition of which is not given, melted to a white glassy mass at Seger cone No. 33, and that in a porcelain kiln another specimen gave a linear expansion at cone 17 of 2.08 per cent. Further heating at same temperature gave an expansion of 2.72 per cent.

The figures quoted above were also given in the last convention of the Lime Sand Brick Society, at Berlin, Germany (see *Tonindustrie Zeitung,* Nov. 31, 1903).

Since these brick consist of 90 to 95 per cent of silica or quartz the heat conductivity must be very low since it is a much poorer conductor of heat than glass. Flint glass has a coefficient of heat conductivity of 0.143, while quartz sand is only 0.0131.

Electrical Resistance.—For electrical resistance 8 plates were tested. These were made 4x4x½ inches with a half spherical indentation in the center, leaving a thickness of approximately one-fourth of an inch in the center where the terminals were applied. The rupture invariably occurred from ⅛ to $\frac{1}{16}$ inch from the line joining the two terminals of the instrument, showing that the current arced through the hydrous silicate bond, as would be expected. The voltage required to puncture varied for the one-fourth inch thickness from 15,000 to 20,000 volts.

Color of Brick.—With comparatively pure sand, the brick are white to grayish white. Deeply colored sands naturally give bricks of a similar color, through considerably lighter. Small amounts of oxide of iron do not materially affect the color. The brick may be colored red, yellow, blue, black, brown or green. In ordinary manufacture, the color is very uniform.

Hygroscopic Property.—The brick are very slightly hygroscopic. The average of twenty determinations shows that about one and one-half per cent. of water is retained in the normal air dried sand brick. The hygroscopic property is the strongest when clay is present.

Absorption.—The water absorption is almost complete in 24 hours, and in 48 hours the brick made in these tests took up from 8 to 10 per cent. of water, in terms of the dry weight of brick. The majority of the results were close to 8 per cent., as may be seen in the tables. The average weight per cubic foot is 136 pounds.

Comparison of the Brick With Natural Stones.—The following table gives a comparison between sandstones in use for construction purposes, and sand brick, as regards their various properties:

TABLE XXIV.

	Natural sandstone.	Sand-brick.
Weight per cubic feet................	137 lbs.[1]	136
Absorption.........................	7.3%[2]	8%
Crushing strength....................	6535 lbs.[3]	7745[5]
Coefficient Elasticity.................	165,440[4]	600,000[6]

[1] Average of 16 samples, Bulletin Wisconsin Survey No. IV, p. 402.
[2] Average of 16 samples, Bulletin Wisconsin Survey No. IV, p. 402,
[3] Average of 51 samples, Bulletin Wisconsin Survey No. IV, pp. 393 and 394.
[4] Average of 28 samples, Bulletin Wisconsin Survey No. IV, p. 399.
[5] Average of 12 samples made and tested for this investigation.
[6] Calculated from curve Figure 4.

As will be observed the weight and absorption are very close. The crushing strength as well as the coefficient of elasticity is in favor of sand brick. While the average strength of a large number of sandstones is less than that of sand brick, there are some sandstones of great strength. A stone from White Haven, Pennsylvania, gave a crushing strength of 29,252 pounds per square inch according to a test reported in the Appendix, p. 30, Brownstones of Pennsylvania.

The coefficient or modulus of elasticity is an arbitrary figure supposed to represent the theoretical load at which an inch cube would be pressed to zero length, if the block were perfectly elastic up to that point. This figure is obtained from the amount of, or the rate of compression or shrinkage in length with the increase of the load, up to the practical elastic limit and the load at the elastic limit.

The practical elastic limit is that point at which the compression curve increases by 50 per cent. or more. An example will make this clearer. Let it be assumed that with a load of 5,000 pounds on a one inch cube, the shrinkage in length up to this point was 0.01 inch, that is, 0.002 inch for each 1,000 pounds of load. Now if on adding another 1,000 pounds to the 5,000 pounds already on, the total additional shrinkage in length is

0.002 — 0.001 inch, or 0.003 inch, the commercial elastic limit would be 5,000 pounds per square inch.

The high modulus of elasticity shown by sand brick means of course that they will make very rigid structures. This property of sand brick is perhaps made more clear by saying, and this is shown in the curve on Figure 4, that a sand-brick cube with a load of 1,000 pounds per square inch only shrinks 0.00125 inch in length. Now, since only 250 pounds per square inch is allowed to be placed on the best Portland cement mortar by most municipalities, the greatest load that we could ask the brick to carry would only cause a compression of ¼ of that given above, or 0.00031 inch per inch of height. This means that in any building, bridge or other structure which is called upon to carry a varying load there will be little or no deformation due to this load. In other words, very rigid structures may be made from this material.

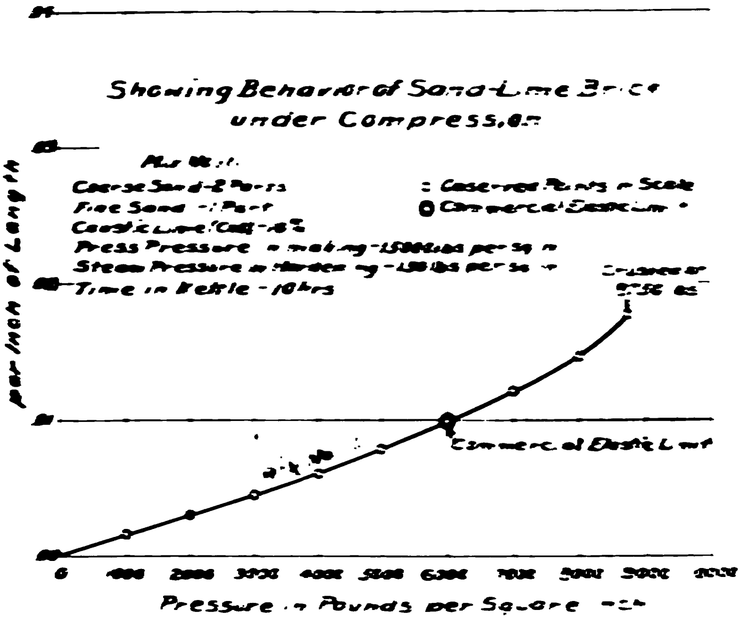


Figure 4—Showing elastic limit of sand-lime brick.

The highest modulus of elasticity quoted in the Bulletin of the Wisconsin Survey, No. IV, p. 399, is one from Ablemans and is 400,900. Limestones go sometimes as high as 1,800,000, and some granites above 2,000,000.

CHAPTER VI.

MECHANICAL EQUIPMENT FOR MANUFACTURE.

As has been intimated in previous statements, the machinery in a general way consists of apparatus for either wet or dry slaking, conveying machinery, mixing machines, presses, trucks, hardening boilers and machinery for generating power.

SLAKING MACHINES.

There are a large number of patented machines in the market for the dry slaking of lime, both in this country and in Europe. I know of but one, however, for wet slaking. In this latter process, the lime is slaked with sufficient water to make a good putty, and after maturing in this condition, it is dried by artificial heat and ground.

Olschewsky, in one of his German patents, uses a cylinder capable of resisting strong pressure, so mounted that it can be rotated, and receive a supply of water at the same time. The cylinder is partially filled of burnt lime and sealed up. Rotation and the introduction of water begins; it rotates fifteen minutes to one hour, and is allowed to stand two or three hours. Thirty to thirty-five parts of water are used to one hundred parts of lime.

From what has been observed in this country, it is safe to predict that such a machine will give imperfect hydration; aside from this the pressure developed in such a machine would be enormous, and unless provided with very large blowoff valves it would be dangerous to operate.

Another of Olschewsky's patents, the German patent No. 82785, consists in the building of a tight metal box in the bottom of the trucks used in carrying the brick into the hardening chamber. This is provided with a stirrer, a shaft with paddles, and water and steam are introduced. The heat generated serves to dry the green brick. This wagon is then run into the hardening chamber, and thus supplies one day's demand for slaked lime. This patent was recently annulled.

This device or procedure was patented in England, in 1900, as No. 1705, and in the United States, December, 1900, as No. 663459.*

In Bulletin IV Series 4, Geol. Sur. of Ohio, on the lime industry, will be found a list of United States patents and claims made by each for lime slaking machines.

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*See *Patent Office Gazette*, Dec., 1900, page 1,946.

Another device which might be mentioned is that of A. G. Schwarz, of Zurich, Switzerland in which the machine is heated by steam pipes and the hydrate is dried by producing a vacuum, all the excess of water being pumped out as vapor. This machine is illustrated and described in "Silico-Calcareous Sandstones," by Ernest Stoeffler as well as in *Engineering News*, February 19, 1903. The above machine is also used in the process of manufacturing sand-lime brick, a total preparing machine, doing both hydrating and mixing.

MIXING MACHINES.

Other machines for mixing used in either process are edge runners, wet and dry-pans, and various mixing machines of the pug mill type. The latter is probably the predominating type of machine in use. Any of the above named machines are efficient, if the mixing is continued long enough. It is only a question of economy in power, and the durability of the machines and available space, which must decide on a machine for any particular case.

The Schwarz machine offers a means of always maintaining constant moisture in the brick before going to the press.

When using other machines the workmen soon acquire great skill in judging the condition of the mix as regards its moisture content. They are able to keep it within safe limits of variation so that with care there is little trouble from this source.

CONVEYING DEVICES.

It is apparent that the best conveying machines will be those which will move the material with as little friction between the conveyor and sand as possible, on account of the latter's strong abrasive properties. Broad continuous belts, where feasible, or heavy chain bucket conveyors are perhaps best adapted to this purpose, where dump cars are not desirable.

If screws or auger machines are used for conveying or mixing, they should be of large diameter and capacity, and not geared to move too rapidly.

Brick Trucks.—The trucks are usually built low and made to carry from 1,000 to 1,400 of brick of American size, or fewer of German size. They usually carry thirteen to sixteen courses.

HARDENING CYLINDERS OR KETTLES.

The hardening boilers are made of iron or steel, and are constructed to stand high pressures—150 to 200 pounds to the square inch. They should always be insulated to prevent radiation and excessive condensation of steam. They have one head movable and bolted on. This head is handled by a small crane and tackle, or compressed air lift. A hinged

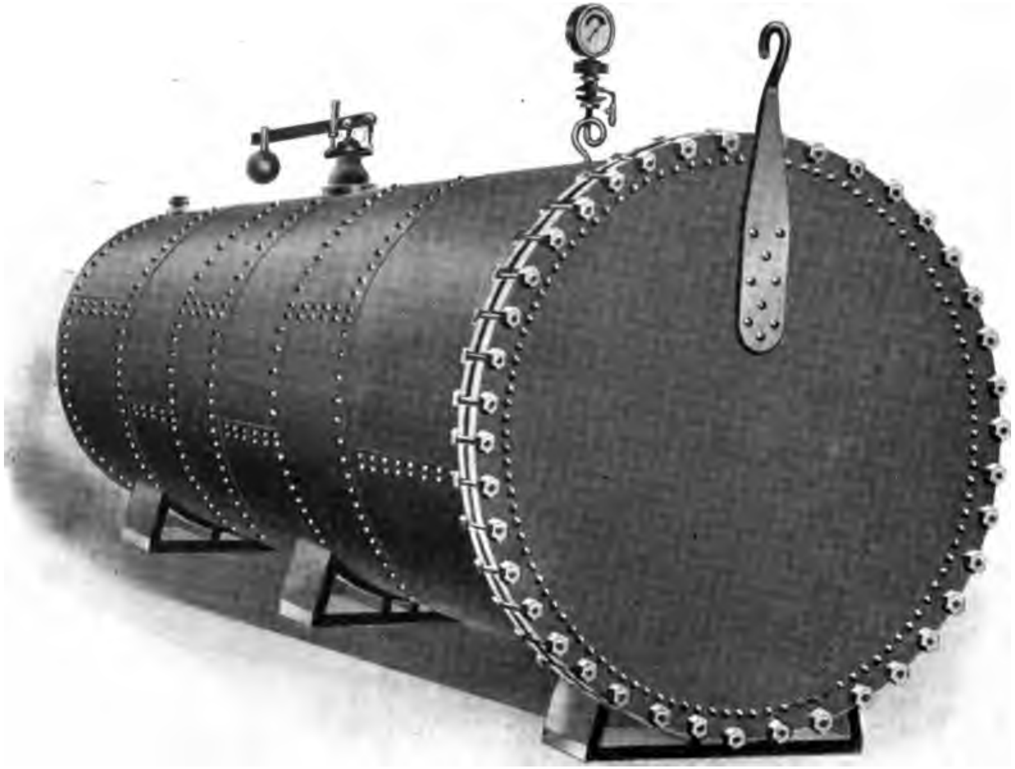

Figure 5—Showing a hardening boiler closed, with the head bolted in position.

door has been used provided with a wheel on the bottom and a track for it to run on. They are very clumsy affairs to move, and occupy a great deal of space, and are not to be recommended. The bolts should be so fastened to the kettle that the head can readily be swung into place. These bolts are usually 1¼ to 1½ inches in diameter.

The size of these hardening kettles varies from 5 feet 6 inches to 7 feet in diameter, by 30 feet to 67 feet in length. There has been considerable discussion among German manufacturers as to the best size of the kettle. From these discussions, I infer that the majority are in favor of the larger sizes. The friends of the smaller size put forward the argument that the brick should be put into the cylinder at once, and that with the larger ones they will have to wait twice as long for the steam treatment. Theoretically this is so, but the writer's experience would indicate that the difference in time of standing, which would only be a few hours after pressing, does not materially hinder the development of the usual strength. When working very moist mixtures the danger of damage from standing is increased, since the less moisture is present the less rapidly will the free calcium hydrate take up carbon dioxide.

With the small kettle or cylinder, the cost of both labor and fuel will will be slightly increased, as has been shown by Thiessen (*Ton Industrie Zeitung,* Vol. 26, No. 104).

The best size of kettle will depend on: 1st, the plan of operation adopted at the plant, 2d, on the capacity of the plant, which depends on the capacity of the press. With a press capacity of 20,000 bricks in 10 hours, the writer would recommend working with units of 10,000 brick, and would build each kettle to carry that many brick. If, however, the press capacity was only 15,000 for a 10 hour day, and the plant was to be operated only through the day, it is obvious that kettles of 10,000 capacity would not be the most suitable. The customary size is six to seven feet in diameter by 40 to 66 feet in length. This range of size will not be far from correct in most cases.*

Figure 6 shows a similar boiler open and charged ready for steam as soon as the head is bolted into place. This cut also shows a container for slaking lime, under the floor of the truck.

PRESSES.

It is a gross error to think that any press will do, as the construction of the machine is of vital importance, not only to the quality of the bricks produced, but also as to the commercial success of the plant, in keeping up a regular daily output without loss of time in breakdowns. It is safe to say that there is no press made today which fulfills all the requirements of this industry. I do not wish to be understood as saying that there are no

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*At time of writing a 120-foot cylinder with two detachable heads was contemplated and has at time of going to press been installed at Mobile, Ala. Nothing could be learned as yet as to the success of this long cylinder, in practice.

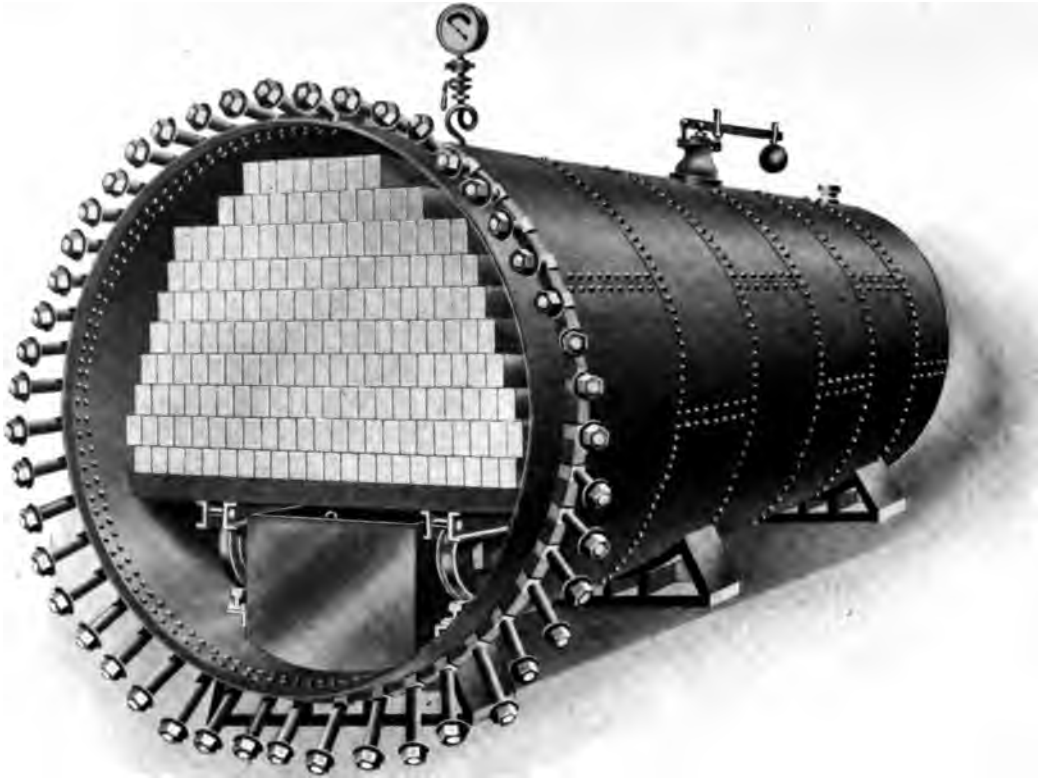

Figure 6—Showing a hardening cylinder, charged, ready to fasten the door. A receptacle for slaking lime is shown under the truck.

American or European presses which will make good brick, because there are a number of them made on both continents. If we could combine the good points of each and improve a few minor defects, we would have a very good press. What I wish to bring out strongly is that there is room for much improvement, and one can trust to American inventive genius to make them, shortly after the faults are found.

The requirements which a good press must meet are as follows:

First—The press must be able to deliver a pressure of 200 to 250 tons for each brick and not break down if by accident a little more is asked of it. That is, it must have a large factor of safety in all of its parts, when delivering this pressure per brick.

Second—The filling of the mold must be accomplished with great accuracy and uniformity.

Third—All working parts must be so arranged that they will be free from contact with loose sand, otherwise they will cut out at an alarming rate.

Fourth—The dies and mold linings must be made of the hardest material obtainable.

That a pressure of 200 to 250 tons per brick is essential to the strongest brick was clearly shown in the discussion of the behavior of the mixture in the mold. Statements and results previously given also show that there is necessity for a press to stand more than the normal load, since the strain on the machine increases at a very rapid rate with a slight increase in the amount of the mixture introduced or any increase in its volume, weight, or density in the loose state which might be brought about by some accident in the preparation of the mixture. The above also accounts for the necessity for accuracy in filling the mold. The lack of plasticity in sand, and its consequent resistance to flow and adjustment under pressure is evident, and hence an even distribution of the loose powder in the mold is absolutely essential. In the above remarks, the writer refers, of course, to presses with direct mechanical motion, driven by gears, in which the length of the stroke and the size of the brick is fixed, and the pressure is dependent on the amount of material placed in the mold. This is the general type of machine in use. If the above requirements are not met in this type of machine many breakdowns may be expected. If, however, one had a press which would apply a certain desired load and no more, or one which had a direct pressure and some means of taking up the strain when it reached anything near the danger limit, the operation of the brick presses would be much more satisfactory than it is now.

The third requirement is self-explanatory and evident.

The fourth is necessary to the reduction of friction and more even distribution of pressure as well as to save the annoyance and loss consequent to frequent changing of the mold lining. The increase of mold pressure increases the friction and abrasion of the mold linings and dies. It was found necessary in our experimental work with cast iron molds, to raise the mold clear from the bedplate, so that the brick rested on the bottom plunger, so as to get pressure both from top and bottom. It seems, therefore, desirable for best results, that the pressure must come from both top and bottom.

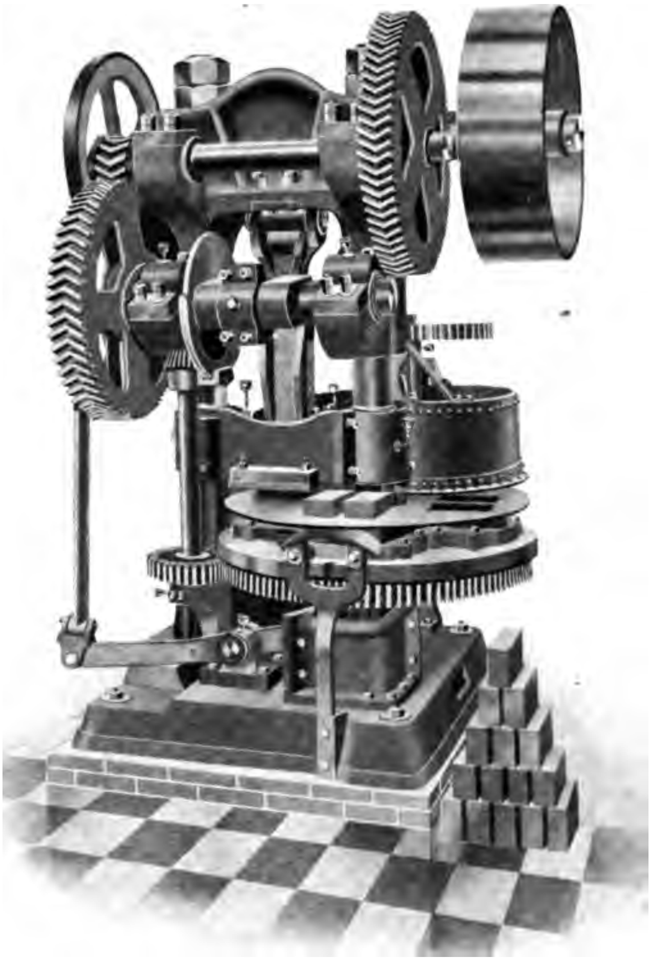

Figure 7—Older form of Komnick Press.

It is probable that the friction on the sides of the mold and the lack of flow of particles will limit the thickness of a block which can be manufactured satisfactorily to 4 or 5 inches, unless the press is so made that one charge may be added and given a definite pressure and then another added and the pressure delivered on top of it. In this way large blocks might be built up. The limiting factor here would be the ability to push the block out of the mold. Blocks made in this way would, of course, be expensive The limit in thickness might be raised when necessary, by increasing the lime and moisture content. These would tend to reduce friction and increase the movement of particle on particle, but at the same time would increase the cost of production.

On account of the resistance of this non-plastic mass to flow, or the movement of particle on particle, it would be well that a press should not release the pressure at once, and it might be still better to repeat the pressure.

It seems that the hydraulic press might have some very strong advantages if adapted to this industry.

Considering the presses in use in this country, we can truly say they all have merit, and if we were able to combine the good points of all in one machine, we would have a very satisfactory one. All have their faults, however. One fault is common to all; namely, they are not built to deliver the very high pressure which has been shown to be desirable. Since maximum strength is developed in a brick by giving it a very high high initial pressure in the mold, brick of strength equal to those now made can be made with much less lime, if the mold pressure is increased. It is undoubtedly cheaper to give this pressure, on a properly designed machine than to use the larger amounts of lime.

Aside from this common fault of weak construction, each machine has its own weak points. The Kahl press, which is a German machine, soon to be manufactured with some improvements by the Semisteel Company, Cleveland, O., is a machine built to stand 150 tons per brick, and one which seems to do very good work up to about 100 tons, or a little more perhaps. This machine is built broad and low, with the wearing parts well protected from the sand. The floor space occupied per 1,000 of bricks capacity is large. This is always a disadvantage. The press consists of a rotating table, which first passes the empty mold under a special measuring device which has the loose material already measured and discharges it when the mold is in the proper position. The table then rotates about 135° farther, and the brick receives its pressure from below, this portion of the table passing under a very heavy overhead arm which carries a hard plate at point where the brick presses against it. The table next carries the brick out from under the arm, after which the brick is pushed up until its bottom surface is flush with the table, so that it may be picked off the head of the die without any scraping, or spalling. The pressure is delivered directly by an excentric working under the table. This is a weak point, which is to be remedied in the new machines, which are called upon to furnish heavy pressures. This machine when seen in operation was producing brick with clean cut edges and corners, with almost no failures. One size has a capacity of 12,000 to 14,000 per day of 10 hours, and the other 20,000 to 23,000.

Another German type of machine, the Komnick press, is that now used by the American Sandstone Brick Machinery Company, at Saginaw, Michigan. (See Fig. 7.) This is an upright machine with a smaller rotating table and a filling device similar to the one employed by the other. The method of delivering the pressure is different, and is given from above. A comparison can best be made by a study of the illustrations.

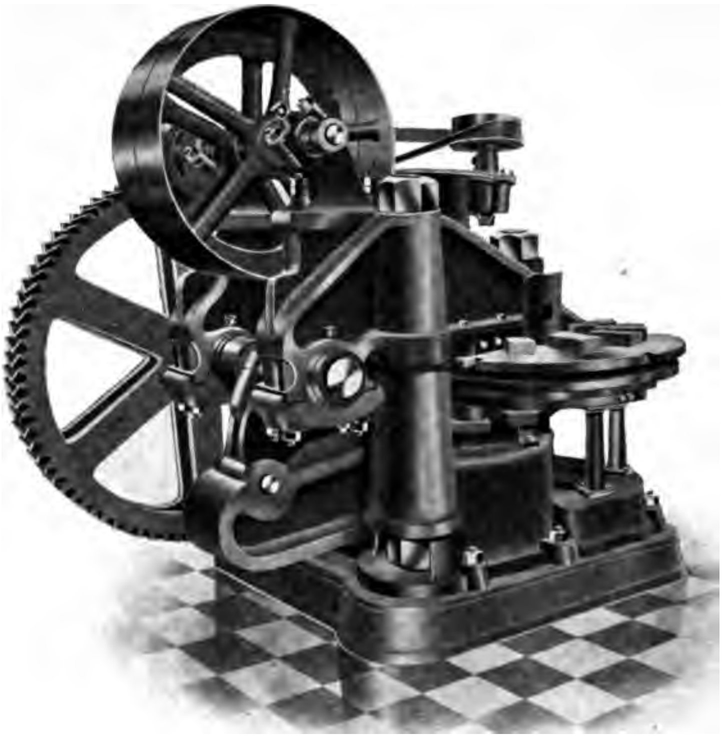

Figure 8—New form of Komnick Press.

This machine is supposed to carry a pressure of 100 tons or more per brick.

The Kahl press only makes one brick with each application of pressure. The Komnick makes two, as may be seen in the illustration. It occupies a little less floor space than a press of the American type with twice the capacity. This press has a capacity of about 10,000 in 10 hours.

A weak point in this machine is that some of the wearing parts are not protected from the sand. When the writer saw it in operation, it was not making brick with clean edges, but this was not a fault inherent in the machine, being due to the setting of the mold linings, and the condition of the die heads. There is room for improvement on the device, or its adjustment, for pushing the brick out of the mold.

Fig. 8 shows another form of Komnick press, which this firm is manufacturing with some improvements, making it double geared and simplifying it at several points. This has replaced the other press in all their new plants.

Since sand brick when first pressed are so tender that they do not not stand pushing and handling without injury, the rotating table is the one thing which recommends and characterizes the German presses; it was the result of an effort of the German sand-lime brick manufacturers to get a press suited to the needs of the industry.

The various American brick presses are too well known to require any description. They have greater strength, greater durability, and greater capacity per foot of floor space occupied, than any other. They have, however, one glaring fault. They push the brick off the head of the die in such a way that many sand brick are injured by having a corner broken off, or the edge on one end made ragged by the breaking out of little spalls.

Two American brick-press companies think they have solved this problem, and will soon have new machines on the market. It is to be hoped that their assumption is true. If it is not it will not be necessary to wait long until the problem is solved.

The writer is in favor of the use of the American press, even if many brick must be thrown back, as he believes the American press will make more brick with less expenditure for labor and repairs than any other.

CHAPTER VII.

PROCESSES AND PATENTS.

Five systems or processes of manufacture have received commercial exploitation in this country. Three of them have plants in operation.

The American Sandstone Brick Machinery Company, of Saginaw, Michigan, is putting in plants after the system used by F. Komnick, of Germany. This company has built a number of plants. The Ohlemacher Brick Company, of Michigan City, Indiana, represents the Kleber system, as patented in the United States. This company has the pioneer plant in the United States. H. E. Brown, of Coldwater, Michigan, is exploiting his patent on the use of *dolomite lime* for sand brick. The Schwarz System Brick Company, New York, has the Schwarz system to offer. H. Huennekes & Company, of New York, are exploiting the Huennekes system, which is based on the United States patent of Jos. Prior. This company has a number of plants in operation today.

There are quite a number of patents which bear directly or indirectly upon the sand-brick industry as defined. There are not so very many, however, that have real merit. There is no patent on the process of hardening in the ordinary way with steam under pressure as has been previously described, nor can there be, since the originator of this idea, Dr. Michaelis, of Germany, allowed his patent to expire some years ago, thus giving it to the public.

There have been granted, however, in the United States, two patents on the hardening process, which bring about the same reaction and by essentially the same agent—hot steam or steam under pressure. While both of the processes will harden the brick, I cannot see where they introduce any advantage or economy over the old way of doing it. In fact, I think there are several factors introduced which would bring about a loss of heat rather than economy.

These patents are:

1—Carl Rensing, Berlin, Germany, 681,580, August 27, 1901.

2—Walter Schulthess, Zurich, Switzerland, 683,337, September. 24, 1901.

An electrical hardening process was patented by

3—Emery Conlon, of Blaton, Belgium, 661,443, November 6, 1900.

The latter, as outlined in the specifications, would probably be too expensive to receive any commercial attention in this country.

So far as the writer was able to find out, none of the three hardening processes have received any commercial application.

In the United States there were granted between January 1, 1892, and September 30, 1902, twelve patents which bear directly on the sand-brick industry. Three of these have objectionable features, considered from the standpoint of the quality of material produced. Good brick can be made by any of the other nine. The question simply resolves itself into one of economy of manufacture, so far as they are concerned.

1—Patent No. 693,906, February 25, 1902, granted to Edward Root, of Dassel, Germany, covers mixtures of clay and lime hardened in steam. The quality of material produced by clay and lime hardened by steam has been discussed earlier in this report and needs no further comment.

2—Patent No. 685,094, October 22, 1901, granted to Sven Edmund Boirie, of Rognhildsborg, Sweden, makes use of nitric acid in the mixture. This is almost sure to leave soluble salts in the finished product, which would be very undesirable.

3—Patent No. 470,333, March 8, 1892, issued to Charles George, of Berlin, Germany, gives to the bricks, after steam hardening, a bath in a solution of calcium chloride. This after treatment is very objectionable.

While good brick can be made under the next three patents, I do not think they are feasible commercially.

4—Thomas Barber, London, England, 624,900, May 16, 1899.

Claim number one of this patent is as follows:

> "The process of manufacturing artificial stone, which consists in first submitting the materials to a vacuum to exhaust the air therefrom, then submitting them to the action of hot water under pressure, then submitting them to the action of steam under high pressure and removing the water, and then again submitting the materials to a vacuum while maintaining them at a suitable temperature till dryness is reached, substantially as described."

The brick must stay in the mold during the entire procedure.

5—Patent No. 591,168, October 5, 1897, granted to Christian Heinzerling, of Frankfort-on-the-Main, Germany. There are three claims. Claim number one would make a good brick, but causes them to remain in the mold, and subjects them to a vacuum after molding. Claim number two dips the brick in oleagenous substances, which would be objectionable for most purposes. Claim number three hardens by carbonic acid gas.

6—Feodore Boas, of St. Hyacinthe, Canada, No. 707,898, August 26, 1902. This patent covers the use of magnesium silicate with lime and steam hardening. There are eight claims. It is impossible to judge offhand as to the results brought about by the first four claims, but the other claims involving sand and lime, with magnesia in excess of the lime, would result in making good bricks. However, there are not many locations where magnesia or magnesium silicate can be had cheaper than sand.

Since, probably, the only office of the magnesia compound would be to replace the sand, it would do just as well to use the sand.

7—Wilhelm Olschewskey, Berlin, Germany, Patent No. 684,649, October 15, 1901.

The only new feature introduced in this patent is the heating of a portion of the sand mixed with the lime in a closed vessel. The balance of the sand and water are added later to cool the entire batch. The additional manipulation will, of course, slightly increase the cost of production. It is necessarily an intermittent process. Since brick are made to answer all requirements without this extra heating and manipulation, this process is not likely to become popular in this country.

8—Oskar Hugo Anderson, of Stockholm, Sweden, Assignor by Mesne Assignments, to Silicate Brick Syndicate, of Montreal, Canada, Patent No. 702,611, dated June 17, 1902; application filed, December 4, 1901.

The essential feature in the claim of this patent is the slaking of lime in dry high pressure steam at the same time and in the same hardening cylinder used in hardening the bricks. The principle of slaking lime in dry steam is not new, since Walters published the properties of lime prepared or hydrated in dry steam a number of years ago. The novelty of the patent must therefore lie in the slaking at the same time the brick are hardened.

The inventor, in his specifications, fails to call attention to the most valuable feature of the entire process, namely, the fact that all of the heat of the chemical reaction of the water on the lime is utilized. As we know, the heat generated is considerable, and all the heat given off by the slaking lime in the hardening cylinder means that just so much steam is saved from condensation by radiation, or in the raising the temperature of the bricks and trucks up to the temperature of the steam.

To pass the steam through the hardening cylinder with sufficient rapidity to keep it essentially free from moisture would be an expensive operation. It is not necessary, however, that this be done, since moist steam will do no harm so long as the temperature is maintained sufficiently high.

The practice recommended in this patent, with the exception that the lime is practically slaked by water before being introduced into the hardening cylinder, is represented in this country by the practice of the American Sandstone Brick Machinery Company, of Saginaw, Michigan.

In April, 1900, F. Komnick, of Ebeling, Germany, issued a pamphlet, "Sandsteinziegel-Industrie," in which he shows a container for slaking lime under high pressure steam, at the same time that the bricks are hardened.

At Saginaw, Michigan, there is a very neat little plant, capacity 12,000 to 14,000 in twelve hours, operating after the system of F. Komnick. This plant has some minor faults in its arrangement, recognized by the owners. These will be corrected in all future plants.

The procedure at this plant is essentially as follows: The lime is prepared by adding water to the quicklime in iron boxes of such size as will fit under the brick trucks in the hardening cylinders. After the addition of the water the boxes are allowed to stand for a short time and are then placed in the hardening cylinders. Any lime unslaked by the water is fully hydrated by the steam during the hardening of the brick. If, on the other hand, a little too much water is added, the steam dries the hydrated lime. This gives a very satisfactory lime hydrate to work with. There are always some lumps which do not entirely break down, so that the hydrate must be ground before mixing with the sand.

The ground lime hydrate and sand are shoveled into an elevator boot, which carries it to the mixing machine. This machine consists of two shafts, studded with paddles turning towards each other. The paddles are so set as to gradually carry the mixture to the other end which feeds into the press. The press used has been described. Short hardening cylinders (27 feet) are in use here; this is not an essential feature of the system, however.

The observations of the writer on the material produced were that the lime was not evenly distributed. This must be due to one of two causes, *i. e.*, either insufficient grinding of the lime or insufficient mixing later. Both finer grinding of the lime hydrate, and a second mixing machine, would perhaps be desirable.

With almost any other method of preparing the lime, the imperfect distribution of the lime would be dangerous to the product, but with this method of preparation, the only undesirable feature is that the full value of the lime as a bonding material is not obtained.

This system of manufacture evidently will not be the cheapest, since the users of quicklime eliminate the cost of the preparation of the lime as indicated above.

9—Herman Elisha Brown, Coldwater, Michigan, Patent No. 697,319, April 8, 1902. This patent covers the use of lime produced from the calcination of dolomite limestone. There are no plants working on this process today, but the contract has been let for the machinery for one to be put up at once at Jackson, Michigan.

As previous statements would indicate, this type of lime must be thoroughly slaked before mixing with the sand, and more time will be necessary for slaking than with the hot limes. The mixing machine contemplated in the new plant is one which has been used in mixing asphalt and sand. Since it is a machine which holds the materials until they are dumped, it should give good results, if the mixture is retained until the lime is completely distributed. The hardening cylinder contemplated is extreme in length, 76 feet. In the opinion of the writer, this is a mistake for any plant, except perhaps one with a capacity of 150,000 or 200,000 bricks per day. The back end of such a cylinder will have very bad light, and further it will be very difficult to keep such a long cylinder from creeping on its foundation.

The process obviously will not be the cheapest one since, as has been previously indicated, slightly more of this lime is needed to produce the same strength, than of hot lime. However, there are, no doubt, locations where this kind of lime can be had at a price sufficiently low to counterbalance any *slight* drawbacks which it may have.

10—Paul Joseph Prior, of Cologne, Germany, Assignor to Heinrich Huennekes, of Straelen, Germany, Patent No. 686,333, November 12, 1901.

The essential feature of this patent is the introduction into the hardening cylinder of alkali salts, potassium and sodium carbonates, in such a way that the steam introduced shall pass over the salts. The claim is made that in this way the potash and soda are introduced into the brick.

This patent has been largely exploited in this country, and is better known under the name of "System Huennekes."

Knowing the properties of potassium and sodium carbonates, we can not believe that they are carried up and into the brick to any extent by the steam. The writer also concluded after seeing a plant at Pittsburg, Pennsylvania, which is operated according to this patent, that the alkali salts were dissolved and carried out by the condensed water, a considerable amount of which is inevitably formed in the hardening cylinder. This being the case, the alkali salts could do neither harm nor good, so long as the steam inlet and salts were kept *under the trucks* carrying the brick. If, however, the alkali salts were suspended *over the bricks,* and the steam then blown over the salt containers, there might be positive harm done, by the mechanical action of the steam splashing the solution of potassium and sodium carbonates over the surface of the brick, which would later be apt to show up as a white scum on the brick. Owing to the fact that three plants were working in this country under the protection of this patent, and that the promoters of this system were making rather strong claims as to the desirability and advantages of this system over all others, it was deemed advisable to make a comparative test of material made by the Survey according to this patent, and material prepared in the ordinary way.

Accordingly, a mixture of four parts of the coarse sand used in earlier work, and one part of fine ground sand and 10 per cent. high calcium lime was made up and three cubes and three briquettes were made with a press pressure of 15,000 pounds per square inch, and hardened in a hardening cylinder, in which the inlet delivered the steam over the surface of the potassium and sodium carbonates in shallow pans. This was accomplished by closing the end of the steam delivery pipe which was placed on top of the shallow pans. This pipe had a large number of holes on both sides, so that the steam was distributed over the surface of the salts. The cylinder

. was heated to above 100° C., before putting in the bricks and the alkali salts, so as to have as little condensation as possible, but the pans were filled and running over with water when the process was finished, and the cylinder cooled and opened.

Three more cubes and three more briquettes were manufactured under exactly parallel conditions, except that *no alkali salts* or *chemicals* were introduced into the hardening cylinder. The average results obtained from crushing tests of three cubes of each series and tension tests of two briquettes of each series was as follows:

	With alkali.	Without alkali.
Crushing strength, pounds per square inch..............	6181	6415
Tensile strength, prounds per square inch...............	554	644

From the above results it is evident that the introduction of potassium and sodium salts into the hardening cylinder in the prescribed manner brings about no material *good* or *injury* to the brick.

We may say then that this process means a slight increase in the cost of production without material gain in the quality of the product.

As has been stated earlier, there are a number of plants operating under the protection of this patent—one at Pittsburg, Pennsylvania, one at Wilmington, North Carolina, and another at Sioux Falls, South Dakota, and other points.

The general practice at these plants is to mix ground lime and sand with the requisite amount of water to produce the proper consistency in a pug mill. The mixture is conveyed to bins where it is allowed to ripen from 24 to 48 hours, after which it passes through a second mixing machine of some sort to the press. The Berg press is in use at Pittsburg. The second mixing machine at the above named place is a dry pan, and by this procedure fairly even distribution of the lime was being obtained. A rather large hardening cylinder was being used here also—about 6 feet 6 inches in diameter, by 66 or 67 feet in length.

The writer can see no reason why this should not offer a slightly cheaper method of production than the two preceding ones.

11—Wilhelm Schwarz, of Zurich, Switzerland, Patent No. 670,299, March 19, 1901.

Claim number three, which gives the essential features of the patent, is here quoted.

> "The process of making artificial sandstone, which consists in drying the sand by heat in vacuum, then adding lime to the dry sand and drying the lime, then mixing the whole and adding moisture, all the while under a vacuum."

The main object of this patent is to bring about accurate control of the moisture content of the raw brick. While this is desirable, the writer does not consider it essential, since his observation is that the workmen soon acquire sufficient skill to keep the moisture content of the mixture within the limits which will produce good bricks. The *very small* amount of carbon dioxide which is eliminated by the machine being closed while mixing is in progress, is not worthy of any consideration.

The real merit of the Schwarz system lies in the mixing machine which Schwarz has devised to carry out his ideas, rather than in the patented process. This machine is described in *Engineering News* for February 19, 1903.

If this machine were divested of its complex vacuum and heating arrangement, it might be the best mixing device for the sand-brick industry which has yet been offered to the public.

Since the total preparation of the raw material is brought about in one machine, it admits of simple plant construction, eliminating in a large measure conveying machinery, which is very desirable.

The Schwarz System Brick Company is promoting this system,

12—Peter Kleber, of Malatatt-Burbach, Germany, Patent No. 663,-904, December 18, 1900.

The claim made by this patent is as follows:

> "The herein described process for the production of artificial stone or brick consisting in, first, mixing moist sand and unslaked lime so as to hydrate a portion of the lime only, secondly, adding sufficient water to hydrate the lime remaining unhydrated or unslaked, and allowing said mixture to stand sufficiently long to complete hydration; thirdly, bringing the mixture into a plastic cohesive condition by the addition of a minimum amount of water, molding said mixture into blocks and finally subjecting such blocks to the action of high-pressure steam, substantially as described."

A careful study of this claim will show that there is very little in it which is essential to sand-brick manufacture. No new principle is involved. Nothing can be gained by furnishing the moisture to the lime for hydration in two portions instead of one, in fact the reverse is the case since lime slakes best and most completely with a slight excess of water, such as would be needed to bring the entire mixture to the desirable condition for molding after the lime had taken up what water it would. With some limes high in magnesia it would be necessary to let the mixture stand at some stage after the addition of the water necessary for hydration to give the slowly slaking magnesia time to complete its hydration before going to the press. With a hot quick slaking or a high calcium lime this would not be necessary, the hydration would be completed by the time the mixing had been thoroughly done, and the mixture put through the press and into the hardening cylinder while still warm from the heat generated from the slaking lime.

The Ohlemacher Brick Company, Michigan City, Indiana, originally manufactured under the protection of this patent, but the writer does not believe that in their present practice any just cause for action for infringment on the above Kleber patent could be found, were they inclined to abandon its protection.

The Michigan City plant is the pioneer plant in this country. The practice at this plant, briefly stated, is to mix sand, ground quicklime, and water, sufficiently to completely slake the lime and leave the mixture moist enough to mold when finished. This is done in the first mixing machine. The mixture passes through two more mixing machines, and a screw conveyor before going to press. If the moisture content is not right, it is corrected in the last mixing machine, by adding a little water, or a little lime and dry sand, as the case may be.

The mixing machines are of the pug mill type with many more paddles than are in an ordinary clay pug mill. The distribution of the lime was complete.

The raw mixture is carried to a row of presses by an overhead drag conveyor, which has feed openings at each press, which can be closed when the press is not in use. The hardening cylinders are of normal size.

A properly equipped plant operated according to the last patent or in the manner just described should produce brick at a minimum of cost, since there is no extra handling of anything. The raw materials start at one end and come out as finished product at the other end, with no delay except for a steam bath. A considerable portion of the heat due to the hydration of the lime is saved. Any other but a quick slaking lime would make trouble, however.

The writer wishes it understood that good brick *can* be produced under all of the last nine patents described, and that the relative value of each lies in the cost of production, or exceptional quality of products. Of the last five described, if they were all to work under exactly parallel conditions, the writer does not believe the difference in cost of production, between the lowest and highest, would exceed 35 cents per thousand. Likewise the difference in cost of plant construction will not vary more than a few thousand dollars under similar conditions.

The cost of plants will vary slightly from time to time, but will vary markedly with the locality at any time. A well equipped sand brick plant with a capacity of 20,000 brick in 10 to 12 hours, will cost, independent of site and buildings, in Ohio, from $20,000 to $25,000.

The cost of production also will vary considerably with the location. The cost of production in this country, not including depreciation in plant, interest on investment, loss of time in breakdowns and repairs, etc., varies from $3.00 to $4.00 per 1,000. The selling price ranges in different localities from $8.00 to $15.00 per 1,000.

From seven to eight million brick were made and sold in the United States in 1902.

It is a fact worthy of notice that of all the patents mentioned only one was taken out by a citizen of the United States.

The writer can see no valid reason why plants should not be built, or why good brick should not be made, independent of all the above mentioned patents or systems.

ADDENDUM, WRITTEN JANUARY 1, 1905.

Since writing the above article, The American Sand-lime Brick Company, of Chicago, Illinois, has entered the field with an all-American system and no patents. They should be classed with the last five mentioned.

Several other firms not previously mentioned are now in the field, field, among which is the American Clay Working Machinery Company of Bucyrus, Ohio, and the Morris Sherman Manufacturing Company, Chattanooga, Tennessee.

While bricks can be made in a commercial way, which will give crushing strengths of 7,500 pounds per square inch, and tensile strengths of 450 pounds, and at a cost not to exceed $4.00 to $4.50 per 1,000, brick of a lower strength will answer all ordinary building requirements and can in most cases be produced for less money. The writer would consider any sand brick which gave a crushing strength of 3,500 pounds per square inch, or over, entirely satisfactory. Many sands, with 10 per cent. of lime, will give much higher strengths with proper press handling, without the grinding of any of the sand.

A volcanic ash, from Colorado, made up with 10 per cent. of lime, gave a brick which stood frost in an entirely satisfactory way, and showed no signs of efflorescence after the freezing test. This volcanic ash brick crushed at 4,575 pounds per square inch, and gave a tensile strength of 450 pounds per square inch.

No brick were made from blast furnace slag, but the writer is of the opinion that granulated blast furnace slag could be worked up into brick, which would answer for many purposes, if the conditions necessary for successful manufacture were carefully worked out at an experimental plant of the right sort. In the use of this material it would be necessary to give careful attention to all details of manufacture at all times in order to have a uniform product.

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